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# Final Report

# METHODOLOGICAL FRAMEWORK FOR COMPREHENSIVE TRANSPORTATION PLANNING

Prepared for
The Governor's Committee for Transportation
Commonwealth of Pennsylvania
Technical Advisory Committee Project 6 (b)

Transportation Research Institute
Carnegie-Mellon University

Pennsylvania Transportation and Traffic Safety Center
Pennsylvania State University

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# PREFACE

The study reported herein was a joint endeavor between the Transportation Research Institute at Carnegie-Mellon University and the Pennsylvania Transportation and Traffic Safety Center at the Pennsylvania State University, conducted for the Governor's Committee for Transportation, Commonwealth of Pennsylvania.

The effort reported herein was addressed to Operational Project 6(b) of the Technical Advisory Committee's total study program. This particular project was concerned with designing a comprehensive long-range transportation planning methodology for the proposed Pennsylvania Department of Transportation. As such, two major pursuits were involved. One consisted of the identification of salient planning and policy-making issues which have evolved from previous transportation studies plus further issues specific to Pennsylvania. The other pursuit was the methodological design itself.

The report is divided into two parts in accordance with these two efforts. Part One surveys the state-of-the-art of transportation planning in all contexts, placing the Pennsylvania situation in proper perspective as well as tracing the implications of specific issues to the proposed design. Part Two reports on the methodological design itself. All of Part One and the first and last chapters of Part Two represent the combined efforts of both the Carnegie-Mellon and Penn State groups. The remainder of Part Two gives a detailed technical exposition of the design itself. The work

described in chapters VII and VIII was performed by the Penn State group, while the material in chapters IX and X represents the technical contributions of the Carnegie-Mellon group.

Dr. Lester A. Hoel and Mr. Joseph S. Drake served as Study Director and Principal Investigator, respectively, for Carnegie-Mellon's activities. Dr. John J. Coyle and Dr. Owen H. Sauerlender assumed the respective counterpart roles for Penn State's efforts. A complete list of contributors appears below.

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Furthermore, for a variety of technical suggestions and evaluative criticism, we wish to thank the following professionals in the field of transportation planning. Dr. Frederick J. Wegmann, Assistant Professor of Civil Engineering at West Virginia University, granted us permission to use concepts from his Ph.D. dissertation in the material of chapter X. Mr. Jere Hinkle and Dr. T.R. Lakshmanan of CONSAD Research Corporation offered valuable suggestions regarding Statewide traffic models and socio-economic activity allocation models respectively. Dr. Joseph L. Schofer, Assistant Professor of Systems Engineering at the University of Illinois (Chicago), offered a variety of ideas relevant to all parts of the methodological design. Finally, for their information on network simulation models for the Northeast Corridor, we wish to thank Messrs. Ralph Schofer, Lou Santone, Martin Aronoff and John Donaldson of the National Bureau of Standards.

Mrs. Christine M. Burroughs and Miss Barbara Simpson of the Transportation Research Institute at Carnegie-Mellon University typed the manuscript. Mr. Robert K. Moorhead, Mrs. Susan Lilly, and Miss Carolyn Schledt were responsible for the art production.

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# PART I

# I
# INTRODUCTION

Like nearly all political jurisdictions in the United States, the Commonwealth of Pennsylvania is very concerned with a battery of social problems of unprecendented pressure and complexity. This observation reflects the historical fact that as a society grows, its demands for supporting services or "infrastructure" are compounded. In many circumstances, it is the legitimate function of government to effectuate improvements in such infrastructure by direct investment and/or by promotional efforts designed to induce involvement of private enterprise.

The concept of infrastructure involves a great variety of components, including national defense, education, housing, employment security, police protection, fire and flood protection, health, recreation, water supply, sewage treatment, communications and transportation. All of these components involve government participation to varying degrees and at various jurisdictional levels, and all are continually competing for public resources. This resource allocation process, as carried out through the political mechanism, must examine capital investment costs and social benefits and costs. Ultimately, the purpose of practically all infrastructure components is to provide opportunities -- opportunities for members of a society to live, work and recreate in terms of service levels consonant with aggregate

tastes. Public decision-making on these matters is a highly responsible and complex endeavor. It obviously must be supported by well-informed, comprehensive planning which identifies all relevant social impacts of alternative courses of action.

A number of these infrastructure components are relevant at the State level, and are administered by seventeen cabinet level agencies in the Executive branch of the Commonwealth's government. Of particular relevance here is the fact that the transportation component is quite important at the State level, and involves a wealth of planning and programming activities. However, the organizational distribution of responsibility for the Commonwealth's transportation problems currently is quite piecemeal. Among the agencies which have active transportation functions are the Departments of Highways, Commerce, Revenue, Community Affairs, Forests and Waters, and Military Affairs.

The role of transportation as a major infrastructure component has emerged in recent years as a highly complex and delicate one. This observation reflects both the variety of policy instruments transportation involves (e.g., the existence of various transport modes) and the myriad of consequences transportation contributes to (or inflicts upon) society. The lack of a comprehensive and coordinated approach to this very important dimension of the Commonwealth's infrastructure, if allowed to continue, is expected to impose far greater costs upon society in the long run than should

be the case. This concept of social costs refers to the prices to be paid for failing to derive truly comprehensive transportation solutions. These considerations have prompted the proposal of a Pennsylvania Department of Transportation (PennDOT), which would be the agent for implementing a comprehensive and coordinated analysis of Statewide transportation problems. This document is concerned with the design of a methodology for such analysis.

## A. The Role of Government in Transportation

Since the ultimate purpose of this methodology will be to promote the best possible transportation decisions for the Commonwealth, it is mandatory that we appreciate the fundamental basis of the government decision-making process. It is particularly important to understand why, in a democratic society, government intervenes at all into the transportation arena. For proper perspective, let us consider what factors motivate government involvement in any component of a society's infrastructure.

Government involvement in the development of infrastructure is prompted ultimately by two motives. From the production viewpoint some services cannot be performed economically, except on a scale so large that they constitute infeasible undertakings for private enterprise. The second factor relates to deviations between the profit-motivated perspective of private enterprise and the social perceptions of the political process. Some components of

infrastructure are collective goods, the enjoyment of which cannot be denied any member of a society or community without simultaneously denying access to all members. The quantity of a collective good supplied to one member cannot be increased without affording a "spillover" benefit to other members of a society. The production of collective goods, or of any goods whose provision has spillover effects, frequently is not a profitable endeavor for private enterprise. Prices either do not exist or are seriously divergent from social values. In such cases government intervenes, either by direct investment, regulation, or by promotional efforts which make certain investment opportunities more attractive to the private sector. In these cases government evaluates alternative strategies in terms of social values and social costs.

The transportation component of a society's infrastructure has a rather unique function. Almost all other components represent services for which a demand exists *per se*. Demand for transportation service, on the other hand, is ultimately a derived demand. Transportation facilities are constructed in most cases in order to provide adequate capacity and quality for an anticipated travel market, whether the investment is made by private or public enterprise. If transportation is viewed from this perspective only, the primary motive for government investment is its ability to achieve economies of large-scale operation which

appear infeasible to private enterprise. Public investment in highways is in large part attributable to this premise.

The role of transportation, however, extends beyond this perspective of meeting anticipated traffic volumes. In contrast to other components of infrastructure, which are oriented toward providing opportunities directly, transportation provides access to these opportunities. The nature of transportation, then, is that it ties together a society's entire infrastructure and widens the spectrum of meaningful options available to the members of that society. This point of view is particularly relevant to states or regions which are plagued by pockets of economic depression.* Transportation can have a unique integrating function whereby it synthesizes a spatial distribution of infrastructure. This function is effectuated through the medium of mobility.

Of course, where infrastructure is satisfactory, transportation and the mobility it offers serve to integrate an entire economy. Improvements in transportation service tend to increase the activity levels of firms and

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* For example, the Appalachian Regional Commission is attempting to formulate an effective Urban Systems Plan for Central Appalachia (parts of Kentucky, Tennessee, and West Virginia). The basic assumption of this proposal is that an induced urbanization process, which provides increased access to the existing employment and service centers of Central Appalachia, can help bring that chronically depressed area to a closer parity with the rest of the U.S. Parity is gauged by the opportunities the area affords to its people in improved living standards and employment.

households by expanding industrial and commercial markets, other things being equal. Moreover, transportation affects the locational patterns of those firms and households. Thus transportation policy, like other dimensions of infrastructure, can increase a society's growth rate. Much more than any other form of public policy, however, public investment in and/or promotion of a transportation system has a high propensity to affect the geographic distribution of socioeconomic activity. Transportation policy directly affects the relative competitive advantages of different areas to the extent that it renders some areas more accessible than others.

In summary, the enterprise of providing transportation for a society calls for the involvement of both the private and government sectors. The most immediate purpose of transportation is to provide capacity and service quality consonant with transportation demand. To a large extent, a well-defined market with a well-defined price structure exists and allures private enterprise. Government may enter that market where private enterprise is unwilling to invest in extremely large-scale endeavors such as highways. More generally, however, government involvement in transportation is prompted by its myriad of spillover benefits (and costs), and the corresponding divergence between market prices and social values. Because of the complicated social role of transportation, the importance of a well-informed and

comprehensive planning activity to transportation policy-making is particularly acute.

## B. Pennsylvania Transportation: A Paradoxical Leadership

Throughout its history Pennsylvania has been a leader in transportation. This leadership dates from the Philadelphia-Lancaster Turnpike to the Pennsylvania Turnpike and the proposed Keystone Corridor, all of which represent forerunners of their age. Pennsylvania was among the first states to create a state highway department (1903). Since then, the Department has taken early initiative in adopting the federally-sponsored highway planning surveys in the late 1930's and in conducting origin-destination surveys in the late 1950's and again in the early 1960's. Today Pennsylvania with its 2.5 miles of road per square mile of land area is the fourth most extensive state highway system in the nation, exceeded only by Texas, North Carolina and Virginia.

Such statistics on the amount and coverage of physical plant are not very meaningful, though. It is the performance of the transportation system which is relevant. From this point of view, Pennsylvania's system is in many respects far less efficient than it might be in serving passenger and freight demands. Furthermore, the effectiveness of its interface with overall State development is quite questionable, considering recent trends in outmigration and the rate of decline in the Commonwealth's industrial base. Both of these inadequacies have been costly to the State, and can

be rectified only by a comprehensive and coordinated Statewide transportation planning effort.

Paradoxically, the inefficiencies of the current situation derive very much from the fact that Pennsylvania has been a leader in transportation. This leadership has been the consequence of two factors. First, because of her early development in history, the Commonwealth has had to deal with many pressing problems without significant precedent from other states. Second, her industrial and government leaders have maintained a consistent awareness of such problems and of alternative strategies for solution. The range of solution alternatives available at any given period, however, is constrained by technology and "know-how." Pennsylvania's current transportation system involves a morass of facilities which were committed to existence many decades ago. Since that time, both technology and planning technique have undergone tremendous developments; but we cannot go back in time and revise past solutions in light of those developments.

The essence of the Commonwealth's transportation problem is that it evolved without sufficient coordination from a Statewide perspective. It should be emphasized, furthermore, that current inefficiencies are hardly attributable to piecemeal decision-making of prior generations alone. Until the introduction of the Statewide origin-destination survey to the Department of Highways' planning efforts at the turn of this decade, all transportation

improvements were evaluated as isolated elements without any appreciation of network interaction. Furthermore, it wasn't until the creation of the State Highway Commission in 1964 that highway planning in any futuristic sense (a six-year horizon) was initiated.

These two pursuits (again representing significant strides beyond the practices of other states) served to promote desperately needed coordination in two respects. The Statewide origin-destination highway study adapted a methodology for analyzing sets of proposed highway improvements as elements of an integrated network, thereby coordinating highway investment in any one part of the State with highway investment in all other areas.* The State Highway Commission has coordinated the evaluation of alternative highway construction proposals by conducting regional hearings which weigh broader community interests against traditional engineering economics measures. To a significant extent, the Commission has served to coordinate transportation decision-making at the local level with Statewide planning.

Without question, these strides have improved the Commonwealth's highway decisions very much beyond the piecemeal and strictly engineering-oriented approach formerly

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* This methodology was patterned after the general planning strategy employed in urban areas of 50,000 or greater population (of which the Commonwealth has thirteen) to meet the "comprehensive" and "coordinated" requirements of the Federal-Aid Highway Act of 1962 and the Urban Mass Transportation Act of 1964.

employed. Once again, however, this extension of perspective in the Commonwealth's transportation planning activities has brought into clear view the pressing need for further extensions. In the last five years alone there have been rather startling developments in both technology and systems-analytic expertise which offer very great potential for truly comprehensive and coordinated transportation policy. This potential exists in both of the transportation functions stressed above, namely, the accommodation of future transportation demand and the rejuvenation of the Commonwealth's economy.

## C. The Pressures for Further Coordination

The integration of the Commonwealth's highway planning strategy into a Statewide network context has given highway policy a desperately needed sensitivity to local community interests and to interactions between different segments of the highway network. In spite of this broadened perspective, coordination remains lacking in three major dimensions. First, while selected principles of systems analysis have been implemented by the Department of Highways, planning activities related to other modes remain piecemeal and lack any meaningful interface with one another or with highway planning activity. Second, there is mounting pressure for greater cooperation between Statewide transportation planning and private initiative, particularly since Pennsylvania has a very powerful and forward-looking

capability in its transportation industry. The third gap regards the lack of liaison between transportation planning efforts and planning activities concerned with other aspects of State development. Only by coordinating in these three dimensions can Pennsylvania realize the potential inherent in its transportation resources.

The pressures for intermodal coordination in Statewide transportation planning derive from the fact that a variety of technologies currently serve a diverse market for freight and passenger transportation. Until very recently the emphasis of transportation planning was on urban areas, where only two or three distinct technologies exist, all of which are oriented to passenger service. Each such mode has been analyzed as a self-contained system in these urban studies, despite declarations of intermodal integration in published study designs. At the state level, such integration must go beyond mere lip service. This is so not only because a wider range of technologies prevail at the State level, but also because a substantial portion of Statewide traffic involves transfers between modes during an entire journey. The costs and time spent in access and terminal components of journeys are proportionately quite high. Obviously, greater efficiency in intermodal coordination as an operation requires intermodal coordination at the planning level. This need has already been articulated by Governor Shafer:*

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* Statement by Governor Raymond P. Shafer to the Governor's Committee for Transportation, May 26, 1967.

> We have highway plans; we have mass transit plans; we have port development plans and waterway plans; we have airport development plans; but we lack a comprehensive transportation plan that brings together all these separate, but highly essential, plans so they make sense for Pennsylvania's future. What we need is a Master Plan for Transportation.

Such an integrated planning strategy will also improve resource allocation by matching projected demands for any given type of transportation service to the technology best suited to providing that particular service.

The need for coordination between the private and public transportation sectors is related to the need for intermodal coordination, since some modes involve government ownership while others do not. Over and above this division of ownership, there are further significant motives for active dialogue. On the one hand, the planning of future government investment in transportation must consider expected impacts upon the competitive situation between all modes and all carriers. On the other hand, while private initiative tends to make transportation investments ultimately in reference to a profit criterion, that sector should be encouraged to temper its decisions in directions of efficient Statewide development, as indicated by the PennDOT planning effort. These points are particularly critical in view of the increasing pace of technological innovation in transportation generally and in the Commonwealth's transportation industry specifically. The social impacts of

proposed systems promise to be extensive; measures should be taken to ensure that these impacts will be consistent with Statewide development policy.

This point leads to the third dimension of coordination required, namely, between Statewide transportation planning and other planning efforts concerned with Statewide development. For all practical purposes, there has been negligible interface of this nature to date. Highways, airports, and other public investments in transportation are planned strictly on the basis of projected travel demands, tempered only by local pressures directed primarily to detailed locational decisions. The sensitivity of socioeconomic activity (particularly the spatial distribution thereof) to changes in the Commonwealth's transportation system has been completely ignored. This narrow viewpoint not only dismisses the concept of using transportation as an instrument for shaping the State's growth pattern, but also results in erroneous estimates of future origin-destination patterns. Moreover, the very simple projections of socioeconomic activity that are used have no sensitivity to the development proposals of the State Planning Board and various cabinet departments. Transportation and socioeconomic development are mutually responsive, and must be coordinated most intimately. PennDOT can play a vitally important role in integrating transportation planning with the land use planning activities of the State Planning Board.

Were the prosperity of the Commonwealth satisfactory in all respects, this emphasis might be subjected to some question. Such is not at all the case. In recent years, the concern over a growing rate of net outmigration (418,000 people between 1950 and 1960) has evolved into a major policy issue. Equal concern has developed for an obviously declining industrial base, particularly in those sectors which were once very sensitive to raw materials' location. Pennsylvania's transportation system has failed to respond to the changing structure of inter-industrial relationships and the shifting emphasis of transport-sensitivity in industrial production functions. Furthermore, a large portion of the Commonwealth's land area qualifies as a part of the chronically depressed Appalachian belt.

For a state with such an advantageous geographical location and a wealth of natural resources, these readings fall far below its potential. Governor Shafer has stated quite clearly the need for a revolutionary perspective toward transportation and its role in realizing such potential:*

> As governor of the Commonwealth, I am convinced that the future of our State rests on how well we plan now to make full use of our great geographic location among the states. For we are the "hub" state -- the center of 93 million people and the Nation's major industries -- the most powerful concentration of people and business in the

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* ibid.

> world. Bold and imaginative use of this advantage -- which means bold and imaginative development of our total transportation network -- will mean new industry, new jobs, better and healthier metropolitan growth, and consequently, a better opportunity for all our citizens to achieve their full potential. We are not geared in Pennsylvania to take advantage of this opportunity now.

Judiciously fashioned long-range improvements in Pennsylvania's transportation system, by increasing the real proximity of its subareas to potential suppliers and markets, can be powerfully instrumental in promoting the State's competitive advantage.

## D. The Required Planning Effort

Bold and imaginative development of the Commonwealth's total transportation network requires a bold and imaginative planning methodology. The purpose of the study documented in the following pages was to design such a comprehensive long-range planning strategy in accordance with the three coordinative themes discussed above and the various functions recommended for the PennDOT organizational design. As such, the study was one in a series of seven "Operational Projects" programmed by the Technical Advisory Committee of the Governor's Committee for Transportation.

### 1. Companion Operational Projects

Operational Projects 4, 5, 6(a) and 6(b) in this program specifically related to methodological strategies for making sound transportation policy decisions within a

system context.* The subject matter of these four efforts was defined as follows:

| Operational Project | Subject of Study |
|---|---|
| 4 | inventory and analysis of existing transportation infrastructure |
| 5 | analysis and short-range forecasts of transportation demand |
| 6(a) | development of an Interim Transportation Master Plan |
| 6(b) | design of a comprehensive long-range planning methodology |

Project 4 was performed by Wilbur Smith and Associates, while Projects 5 and 6(a) were undertaken by the Franklin Institute Research Laboratories. Project 6(b), reported herein, was a joint venture between the Transportation Research Institute at Carnegie-Mellon University and the Pennsylvania Transportation and Traffic Safety Center at the Pennsylvania State University. Franklin Institute Research Laboratories was also responsible for coordinating all four efforts.

Operational Project 4 was basically an inventory of the existing supply of transportation capacity and service, and of existing network utilization patterns. The scope of the inventory was as comprehensive as all available data would permit. Specifically, a separate system of

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* Other projects in the program included an analysis of the proposed Keystone Corridor concept, a literature survey, and the design of an organizational structure for PennDOT.

geographic zones was defined for every mode (due to different data endowments), and the capacity and service characteristics of both passenger and freight transportation between every pair of zones were measured (again, where available data so allowed). Given this inventory, the mappings of existing utilization and supply were superimposed and analyzed in order to identify current deficiencies. This result represents one point of departure for fashioning short-run strategies of system improvement. The effort on Project 4 also characterized the current state of relevant data, which has served as a useful point of departure for designing future information procurement strategies for the proposed Department.

While the importance of designing a comprehensive, systems-analytic planning methodology for the proposed Department has been emphasized above, it must also be recognized that transportation decisions must be made during the period of time over which the proposed Department takes root. Accordingly, Projects 5 and 6(a) were directed toward developing a short-range Interim Transportation Master Plan which could serve as a first-order guide to the Department's early investment recommendations.

The effort on Project 5 involved an analysis of the aforementioned supply and utilization data, together with information on socioeconomic characteristics, to determine the manner in which travel patterns in the Commonwealth depend upon economic and demographic activity (holding

supply characteristics constant). Given this analysis, socioeconomic activity for the State's subareas were then projected to 1975 and the implied travel patterns were forecasted. These demand forecasts assumed no change in the existing transportation network, thereby permitting a comparison between the estimated utilization pattern and current supply in order to identify expected deficiencies which a "do-nothing" policy would occasion.* The two mappings of current and expected deficiencies were used as primary references in fashioning the Interim Plan.

Project 6(a), which developed the Interim Plan, involved the identification and evaluation of more than 90 transportation projects, fashioned by surveying existing plans and proposals of various agencies. The expected performance of these projects was estimated subjectively for several categories of indirect benefits in addition to the more objective estimates of demand provided by Project 5. The Interim Plan was developed by means of an ordinal ranking procedure which classified the projects into several priority categories.

## 2. The Comprehensive Methodological Design

Project 6(b) involved the design of a total methodology for comprehensive, long-range planning which incorporates objective, systems-analytic techniques. While the Interim Plan resulted from very simple demand projection techniques,

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* These demand forecasts were limited not only by immediately available data, but also by the obvious constraints which the six-month contract period imposed upon sophistication of technique. The methods employed for these estimates therefore were rather mandane, as their purpose was to provide an immediate first-order approximation.

applied generally to individual network components independently of all other components, the methodology reported herein views transportation in the context of a Statewide multimodal network system. Demand estimation procedures are designed so that expected flows are rendered dependent on specific network characteristics. Moreover, the socio-economic forecasts which precede the demand forecasts are also transport-sensitive, explicitly treating the phenomenon of spatial competition between subareas for industry and households. This comprehensive approach to demand forecasting, when implemented by the new Department, will yield much more meaningful estimates since it considers the "induction" effect of transportation upon the use of land by economic and demographic activity and upon travel demands.

The design of a sophisticated methodology for forecasting the consequences (both direct and indirect) of network changes is only a part of the entire design effort of Project 6(b). These forecasting techniques are couched within a broad evaluation framework which: (a) partially objectivizes the task of hypothesizing alternative network systems, and (b) treats explicitly the interface between the planning effort and policy-makers, and the very crucial role of information in the dialogue between these two parties.

The activities during the six-month project period have been devoted to the following overlapping pursuits:

(a) a thorough analysis of the state-of-the-art of transportation planning methodology in urban, state, and regional contexts; and

(b) the design of a comprehensive transportation planning methodology for PennDOT.

Both pursuits have involved two perspectives. The broader perspective has focused upon the total planning process as a system, exploring such issues as how normative a State planning process can be, alternative renditions for capturing policy-sensitivity, and what the term "comprehensive" really must mean at the State level. This perspective has been oriented to the overall identification of a planning process' components and their interfaces. The more specific viewpoint has dwelled upon alternative analytical techniques for accomplishing the functions of individual components.

The methodology itself has been designed according to several fundamental criteria derived from considerations discussed in the previous section. Three of these criteria constitute a broadening of the term "comprehensive" as used somewhat loosely in urban planning studies:

(1) The methodology must incorporate all existing modes of passenger and freight transportation, and indeed must be sufficiently flexible to allow for the introduction of new modes.

(2) It must provide for the estimation of indirect impacts of transportation upon the environment as well as for the estimation of future transportation demand and system utilization patterns.

(3) It should treat explicitly (and even promote) the interface between planning and policy-making (both in transportation and in other avenues of public policy) rather than pretend that efficient State transportation planning is mere monologue.

A fourth guideline, however, is the most critical one: the availability and merits of information for transportation planning in the Commonwealth. As a general rule, the output of the integrated planning and policy-making process is a set of decisions regarding public investment, regulation and/or promotion. With no risk of oversimplification, it is also asserted here that the brute input to that total process is information. The study has been primarily concerned with the general tradeoffs between investment in information procurement, the costs of analyzing that information through the planning process, and the total costs to society of inadequately informed decision-making.

In addition to the above, two other criteria were chosen as overall guidelines for the methodological design. A transportation planning methodology must be compatible with the organizational structure within which it is practiced. Accordingly, the effort reported herein has taken as given the organizational design prepared as Operational Project 7.* Also, the design of the strategy for implementing the methodology must take as given the techniques and information currently being used for planning

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* For example, the methodological design for PennDOT emphasizes intercounty (as opposed to intracounty and/or intraurban) transportation. One strong motive for this decision was the recommendation by Project 7 that actual planning efforts for such areas should take place at the local level, with technical assistance from PennDOT.

transportation in the Commonwealth. Maximum advantage was derived from existing practice.

One final criterion deserves mention, though it has been viewed as a "spillover" benefit rather than as a direct guide: the flexibility of the design for application to planning problems broader than transportation. In general, the forecasting models involved in the design have been rendered sensitive to transportation and land use policy. One model which forecasts indirect effects (i.e., the responsiveness of socioeconomic activity patterns to transportation change), however, can be used to account for economic and demographic reactions to a variety of policies such as vocational training and government procurement, given some marginal analytical work. This flexibility merely reflects the conviction that transportation must be analyzed in terms of the socioeconomic activity system which it serves.

## E. Organization of the Report

This report on Project 6(b) is divided into two parts, in order to distinguish broad issues from specific technical questions, and to provide proper perspective. The remaining chapters in Part One afford this perspective by reviewing the state-of-the-art of transportation planning in its overall context (chapter II), activities of other states (chapter III), and current practice in the Commonwealth (chapter IV). A number of issues, both general and specific

to Pennsylvania, are raised in these three chapters. Their implications to the methodological design are interpreted in chapter V.

Part Two presents the detailed methodological design, beginning with an overview in chapter VI. That discussion defines the scope and data requirements of the design, as well as its rationale and operation. Chapters VII, VIII and IX define the mathematical models involved in the forecasting model system. Chapter X discusses the use of that model system to fashion, test and refine alternative transportation plans by means of a semi-objective strategy. Finally, chapter XI presents guidelines for implementing the entire methodology in stages over time.

# II
# THE FORMAL TRANSPORTATION PLANNING PROCESS

As noted in the Introduction, the systems-analytic approach to transportation planning originated in metropolitan areas in the early 1950's. Since that time a general methodological structure has evolved from literally scores of urban and regional studies. Considering the prominence of this heritage, a thorough review of such methodology provides the most convenient point of departure for developing a planning framework for PennDOT. This chapter presents such a review, and emphasizes the rationale behind established techniques as well as outlining the techniques themselves.

## A. A General Structural Characterization

Transportation planning, as popularly practiced, may be defined as a process by which alternative strategies for modifying an existing network are evaluated in terms of the relevant consequences and capital costs associated with each such alternative. An elementary decomposition of this definition provides a convenient vehicle for this chapter's discussion. Viewed from very broad perspective, the transportation planning process may be characterized in terms of the following set of tasks:

(1) identification of relevant policy variables

(2) identification of relevant consequences or effect variables

(3) collection of information required for task 4

(4) development of the "forecasting model system" (which relates effect variables to policy variables)

(5) generation of alternative transportation investment strategies

(6) application of the forecasting model system to estimate the relevant consequences of each alternative

(7) selection of a "best" alternative by a comparative evaluation of their consequences and capital costs.

The first two tasks serve to define the scope of a new planning effort. The third task deserves separate identity because the detailed development of forecasting models through empirical analysis (Task 4) cannot proceed without first collecting necessary data, which can involve delicate management problems. Finally, that forecasting model system is only useful insofar as it is used as a tool for fashioning a range of "good" transportation systems which ultimately must be evaluated by policy-makers as well as planners. Tasks 5, 6 and 7, then, constitute a process of plan design and evaluation. All of these activities are key elements of any urban or regional transportation study, and are necessary considerations of the methodological design reported herein. Accordingly, the mainstream of this entire report shall be structured in terms of these steps.

Before elaborating upon each of these tasks, the concept of a transportation "plan," as traditionally defined, requires clarification. The concept conventionally refers to

a broadly specified transportation network prescribed to exist by some future time (the "horizon year"). The term "broadly specified" is intended to distinguish between regionwide system planning and isolated facility design, as explained succinctly by the Chicago Area Transportation Study:*

> ... A region of 7.8 million persons some twenty years hence does not allow the planner to be concerned with the timing of traffic signals or the headways on bus routes. These are important problems, but they are at too fine a level of detail. Likewise, final locations and geometric designs of specific facilities are not a proper task of this report. Instead, a metropolitan planning scale is maintained, spelling out the dimensions of the main elements of regional networks of express highways and rail transit lines.

Although the primary concern of this chapter is with well-established concepts, it should be noted that the aforementioned notion of a "plan" is not universally accepted. Almost all operational studies have maintained a loyalty to the "one-shot" planning approach described above. This term is descriptive of any planning activity which concentrates its efforts into a relatively brief initial period near the base year and whose orientation is overwhelmingly toward choosing a transportation system for some twenty or so years hence. A growing school of thought, which considers this "one-shot" philosophy to be too static, is that the total planning and decision-making process should focus on incremental alterations of the transportation system

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* Chicago Area Transportation Study, Final Report, Volume III: Transportation Plan, April 1962, p. 5.

as it exists at any future time, rather than to focus on all-at-once committment of investment. While this thinking may not have operational impact in the immediate future, it is healthy to be aware of the trend.*

This trend in planning philosophy has been extended even beyond the incremental concept. One idea is that of continuously monitoring a region's transportation system and its environment, and controlling unforeseen shocks to either by a strategy which keeps close pace with "real time." This approach, which has been termed "adaptive planning," would require the design and implementation of a very elaborate information system. It argues for a "compensatory tracking" role of planning, involving "...models that can keep close contact with what is happening and react very quickly to shifts in the states of affairs, in the manner of an automatic pilot which has an ability to accept information and keep an aircraft on course. In such a model, the goals actually realized will be better known."**

A second direction, equally sophisticated and impractical at present, is toward setting goals, transforming them

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* Some studies have incorporated a time-incremental <u>forecasting</u> procedure which divides the period between the base year and the horizon year into discrete intervals. The motive in such cases, however, apparently has been a growing interest in the time stream of consequences. A time-incremental <u>planning</u> procedure is quite a different matter.

**Garrison, W.L., "Urban Transportation Planning Models in 1975," <u>Journal of the American Institute of Planners</u>, Vol. XXXI, No. 2, May 1965, p. 157.

into measurable objectives, and then employing some optimizing analytical scheme for calculating directly the best space and time path for achieving the desired end-states. In other words, transportation policy would be solved for endogenously within the analytical process.* Given an accurate forecasting model system which characterizes mathematically the dependence of effect variables upon policy variables, this approach would apply that model system in inverse fashion, thereby solving for the unique transportation system which would lead precisely to the prescribed objectives. Even for relatively simple goal formulations (such as minimizing total transportation costs), however, any realistic forecasting model system involves too complicated a set of mathematical relationships to permit such an "inverse" solution.

A more viable approach to transportation planning, then, begins not with an objective expression of a desired end-state but rather with a mere identification of relevant policy and effect variables. The forecasting model system relating these variables is next developed, given required data. Accepting as unwieldy the problem of deriving optimal values of policy variables from prespecified conditions for effect variables, alternative investment strategies

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* Bruck, H.W., "Problems of Planning for the Future: Marriage of the White Queen and Tiresia," paper presented at the National Transportation and Railroad Symposium, San Francisco, May 1966 (to be published in Proceedings of the Symposium by the American Society of Mechanical Engineers).

(i.e., alternative sets of values for policy variables) are fashioned on a relatively subjective basis, and the forecasting model system is employed to estimate the resulting effects associated with each alternative. These alternatives are then compared with reference to their respective consequences and capital costs. Like most interesting design problems, then, the general methodology of devising "good solutions" to the transportation problem basically involves a trial-and-retrial search process. Steps 5, 6, and 7 in the aforementioned task framework represent this solution process.

To summarize, this brief digression makes two points. First, we currently do not have the capability to solve for "optimal" transportation systems, Indeed, the trial-and-retrial search strategy likely will be our feasible approach for many years to come, so that we will continue to recommend only "reasonably good" transportation plans. Second, the attitude toward transportation planning strategy, at least as evidenced by some academic circles, is shifting somewhat from the "one-shot" tactic. The entire field is so embryonic, however, that debates over issues of this sort are likely to continue for a long time. It should be emphasized, in any event, that the nature of a "solution" to a region's transportation problem, and the methodology called for in seeking such a solution, depend very critically upon how that problem is structured. Because this chapter is concerned primarily with providing an overview

of existing methodology, only the "one-shot" strategy will receive further discussion.

Having introduced the seven-step task framework and the rationale behind it, the remainder of this chapter elaborates on each of the steps. The discussion follows from Task 1 to Task 7 sequentially, save for one very important digression. In section E the task framework is temporarily suspended in order to delineate the manner in which transportation planning methodology has evolved over the past fifteen years.* This interruption outlines the various ways in which transport-sensitivity has been incorporated (and ignored) in the planning process, which is the paramount issue of any transportation study design.

## B. Identification of Relevant Policy Variables

Perhaps the most fundamental issue involved in defining the scope of a planning study is the identification of what instruments shall be considered for guiding the course of a region. Ideally, all public decisions pertaining to all avenues of investment, operation, regulation and promotion -- and their myriad of interfaces -- would be analyzed together by one grand planning effort. The state-of-the-art of public planning at present, however, has enough difficulty trying to solve individual social problems even when isolated from each other.

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* A technical appreciation for this evolution in methodology requires an awareness of the concepts to be discussed in sections B, C and D.

Just as the previous paragraph has paid lip service to the interface problem, the initial designs of our more recent metropolitan transportation studies have mentioned the intimate interactions between transportation policy and land use policy. Even in these studies, however, future land use policies generally are taken as given, and transportation is planned to be compatible. More specifically, such planning efforts may identify explicitly an exogenously specified open space program (which dictates where not to locate future facilities), and they may estimate the impact of proposed transportation plans upon a region's future land use pattern. It is quite rare, however, that a transportation study actually recommends specific land use controls such as zoning ordinances. This section, then, is devoted exclusively to the transportation policy variables with which the typical metropolitan study concerns itself.

The typical metropolitan area transportation study is ultimately concerned with fashioning a transportation network which will accommodate future needs, given the existing network and available transport technology. A priori, the generalist would probably argue that this concern includes abandonments, status quo maintenance, and improvements of existing facilities as well as the construction of new facilities. He would further argue that the basic set of policy variables includes the areal and temporal distributions of the quantity and quality of future transportation plant and rolling stock, and also the ownership responsibility for operation thereof.

Metropolitan planning efforts are far less general. For the most part, the existing system is projected into the future as it is, and the brunt of attention is devoted to proposals for new construction of freeways and, in some cases, rail rapid transit. Upgrading of arterial highways is generally left to the traffic engineer to consider on an isolated project basis. The question of ownership and responsibility for operation are trivial ones in this metropolitan context: all highways shall be publicly owned, and all planned transit services shall be publicly owned and operated. Also, as stated earlier in the discussion of the "one-shot" planning approach, the temporal staging of future investment is considered only after a horizon year plan has been selected. In sum, the typical metropolitan or regional study is preoccupied with the question of <u>how much</u>, <u>what quality</u>, and <u>what geographic configuration</u> of <u>new</u> freeways and rail rapid transit facilities to provide by some point in future time. Furthermore, only investment decisions are considered; regulatory and promotional policies are not deemed relevant.

As suggested above, the typical metropolitan study approaches its transportation problem with only two fundamentally different physical components being considered: the freeway and some specific form of rail rapid transit (usually the same form that exists in the region already). Each of these two types of components, moreover, typically represents one and only one level of service as expressed by predefined average operating speeds. Indeed, most studies do

not even treat the capacity parameters for either type of component as a variable, but rather adhere to a specific number of lanes for all freeway sections and to one right-of-way dimension and operating policy for all rail rapid transit sections. Thus, the selection of either mode implies the choice of quantity and quality of transportation service for any given network section. Furthermore, in almost all studies highway planning and evaluation has proceeded independently of that for rail transit. For all practical purposes, then, the only variable which the typical metropolitan study really "varies" meaningfully is the geometric configuration of the freeway network and of the rail transit network.

One of the distinguishing features of the Northeast Corridor Transportation Project, when compared to other urban and regional studies, is its consideration of a broad range of service levels and capacities. This meaningful variation is captured in two respects. First, a variety of new transport technologies (as well as a variety of conventional modes) is being considered. Second, each of these many types of technological components is characterized in terms of cost functions which relate its capital and operating costs to measures of the amount and quality of transportation produced.*

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* Northeast Corridor Transportation Project, "Study Design," Technical Paper No. 5, U.S. Department of Commerce, Office of High Speed Ground Transportation, Transport Systems Planning Division, July 1966.

In any event, the question of network geometry always is a central issue in transportation planning, and the relevant policy variables of any study always are expressed is reference to an "abstract network." Given infinite resources, a transportation planning effort would be implemented in such detail that all traffic on all rights-of-way and across all intersections of such rights-of-way, no matter how slight that flow might be, would be accounted for. Any practical analysis, however, must abstract from such a detailed reality some reasonably representative model of the physical network such that the great majority of traffic movements may be traced. This abstraction process essentially consists of aggregating two types of geographic elements. Individual rights-of-way are combined into abstract network "links," and individual intersections or points of transfer are aggregated into abstract network "nodes." Moreover, individual traffic analysis zones which generate (originate and/or terminate) traffic are delineated and abstracted into additional "loading" nodes. In the abstract network, then, links and nodes are defined mutually; links are defined by pairs of nodes and nodes are defined by intersecting links. A link is a unidirectional arc which connects any given node directly to any other node, thereby rendering the two nodes adjacent to each other.

If transportation were infinitely ubiquitous, in the sense that no expenditure of any type of resource were required in order for traffic to flow from one point to another, it would be quite difficult to characterize one

"link" or "node" versus another. The very finite and discrete nature of transportation networks, however, is such that very definite sacrifices are required by network users in order for themselves or their shipments to go from origin to destination. It is precisely in terms of these sacrifices which the abstract network is characterized. These sacrifices are multidimensional, including time, monetary outlay, comfort, safety and convenience. However, almost all studies employ only travel time as a measure of these sacrifices, largely because of data problems, but also because many people* in urban areas evidently perceive this factor to be considerably more important than other measures.

The notion of an abstract network may be characterized in terms of some simple mathematical notation. Consider the two sets (S;D). The elements of the set $S = (p_1, \ldots p_i, \ldots p_n)$ are called "nodes," which are point representations of geographic traffic analysis zones and of significant intersections or transfer points. The elements of S are arranged in some definite spatial pattern, location being specified by i. The fundamental element of the set D is called a "link," which is a unidirectional arc connecting one node i to another node j. The indices i and j and some additional notation are defined as follows:

i = an index for all nodes, whether or not they generate (originate and/or terminate) traffic, where the role of any given node i is as the initial node of a link ij (i = 1,...n)

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* Transportation studies in metropolitan areas generally ignore freight transportation.

$j$ = an index for all nodes, whether or not they generate traffic, where the role of any given node $j$ is as the final node of a link $ij$ ($j = 1,\ldots,n$)

$C_{ij}$ = capacity (maximum flow per unit of time*) of link $ij$

$\omega_{ij}$ = average "impedance" (be it travel time, cost, etc., or some weighted combination thereof) of link $ij$

$\omega_i$ = average impedance of node $i$

Specification of these three parameters for all $i$ and $j$ defines any physical system in terms of the abstract network. The fact that the link and node impedances are parameters, whose values define families of volume-service operating relationships for any given type of facility, should be noted.** This complete set of parameters is called the "network description," and may be applied to integrated multimodal networks as well as networks defined separately for each mode.

## C. Identification of Relevant Effect Variables

A general principle of planning is that a set of goals or objectives should be established at the very outset of a planning effort. However, as sound a principle as this is,

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* Almost all studies define traffic flows in terms of average daily volumes; in most cases factors are applied to estimate peak-period flows.

**For example, "capacity functions" often are used to describe the manner in which average travel time increases with increased flow on a highway link. The impedance parameter typically used as a policy variable in this case is the average travel time at maximum flow.

a review of pertinent documents reveals that initial goal specification has been extremely nebulous in practically every regional transportation study in existence. The logical recourse to this situation is to try to anticipate the kinds of consequences which policy-makers will deem relevant. This in turn suggests a dialogue between planners and decision-makers, but again, there have been few concrete instances of such interaction in past transportation studies. Some studies have begun by drafting an exhaustive list of all possible consequencies, but such lists rapidly explode beyond meaningful proportions.* Discussions of the problem typically fall back on a criterion of "what available data will permit."

The nebulous character of the problem is portrayed quite well by Tillo Kuhn:**

> ...the current literature offers a jungle of project effects which are supposed to be analyzed: pecuniary and nonpecuniary, internal and external, private and social, non-transfer and transfer, on-site and off-site, direct and indirect, market and extra-market, economic and noneconomic, measurable and nonmeasurable, monetary and nonmonetary, tangible and intangible, direct and spillover, individual and collective, primary and secondary.

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* For examples of such a list, see Fagin, H., "Urban Transportation Criteria," Annals of the American Academy of Political and Social Science, vol. 352, pp. 141-151 (March 1964);and CONSAD Research Corporation, Impact Studies: Northeast Corridor Transportation Project, Final Report, Volume II, January 1968, pp. 148-151.

**Kuhn, T.E., "The Economics of Transportation Planning in Urban Areas," Transportation Economics, National Bureau of Economic Research, 1965, p. 304.

His point is that, because of the vast complexity of the problem, planning studies vary widely in their classification strategies. The burgeoning terminology has served to obscure more than to clarify.

Perhaps the most fundamental characterization of types of consequences is the distinction between direct and indirect effects. The former refers to those consequences directly related to actual usage of a transportation system, both from the user's and (where relevant) the operator's points of view. The latter refers to the impacts of transport investment upon the socioeconomic environment of the transportation system. Direct effects are universally accepted as relevant in current planning practice. The relevance of indirect impacts, while a matter of spirited controversy in the late 1950's,* is gradually receiving more and more acknowledgement, particularly by studies dealing with large investments in large regions.

Most of this section is devoted to an analysis of the response patterns of direct and indirect effects. Before so proceeding, just one point should be emphasized, namely, the

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* For a review of this debate, see U.S. Congress, House, Committee on Ways and Means, Final Report of the Highway Cost Allocation Study, Letter from the Secretary of Commerce, 87th Congress, 1st Session, 1961, pp. 69-75. Also, see Friedlaender, A.F., The Interstate Highway System: A Study in Public Investment, North-Holland, Amsterdam, 1965; and, Mohring, H.D. and Williamson, H.F., Jr., "Economics of Scale and the Reorganization Benefits of Highway Improvements," a supplement to The Nature and Measurement of Highway Benefits, Northwestern University Press, Evanston, 1960.

pressing need for a deliberate taxonomy, particularly in studies which consider indirect effects. Where only direct effects are deemed relevant, the overwhelming tendency is to summarize the merits of any candidate transportation plan in terms of a dollar-value benefit-cost computation. Some monetary value is assigned rather arbitrarily to travel time savings and to accident rates to render all direct effects commensurate. The introduction of indirect effects into an analysis, particularly those which are nonmonetary and/or intangible (e.g., air pollution, unemployment, income distribution, or aesthetics), precludes the use of such a simple numerical ranking device. The planner's job then becomes one of communicating to policy-makers a wealth of incommensurate information on each alternative plan. This communication can be enhanced considerably by deliberately structuring that information in terms of some simple classification.

Furthermore, it is not enough to present policy-makers with measures which aggregate over the entire region's population or over all pressure groups. They may want to know how benefits and disbenefits are distributed among people, industrial sectors, areas, etc. Be it very subjective, policy-makers implicitly assign differential weights to such groups; for a variety of reasons, a dollar saved by one group may be considered socially more important than a dollar saved by another group. Thus, stratification of effects promotes more meaningful decisions.

## 1. Direct Effects

Direct effects refer to the responsive behavior of those who use a transportation system and the associated implication to those who operate parts of that system. For practical purposes, these effects are captured by estimating the flows and corresponding impedance values which describe the equilibrium pattern of traffic over any hypothesized network's links and nodes. Thus, the analysis of direct effects involves a characterization of the future demand for transportation, which is then synthesized with the hypothesized pattern of supply to determine that equilibrium pattern. Transportation planning parlance refers to this entire process as "demand analysis" and "demand forecasting," which are really misnomers.

This point refers to a classical econometric dilemma: short of very elaborate and generally impractical experimentation, the "demand" for transportation typically cannot be measured without some reference to transportation supply. Be it a choice of whether to initiate a journey at all, or a choice of destination, mode, or route, observable demand for transportation is conditioned by the particular characteristics of the supply of transportation prevalent during the period of observation. Accordingly, when the term "demand" is used in this report it is applied loosely, and is synonomous with terms such as "traffic" or "usage" or "output," implying a "realized demand" rather than demand in the classical "willingness-to-pay" sense.

Given the hypothesized modification of an existing transportation network serving existing traffic, there are five fundamental types of traffic adjustment which might occur over time, subsequent to implementing such a modification:*

(1) Diverted traffic - that component of existing traffic which has changed from its previous path of travel to another route without a change in origin, destination, or mode of transport

(2) Converted traffic - that component of existing traffic which, for either part or all of its previous path of travel, has changed its mode of transport without a change in origin or destination

(3) Shifted traffic - that component of existing traffic made up of journeys whose "desire lines" have shifted due to a change in origin and/or destination (e.g., relocation of a producer and/or a buyer)

(4) Induced traffic - that component of added traffic which did not previously exist in any form, but which results in unique response to the provision of improved transportation facilities

(5) Natural traffic - that component of added traffic which did not previously exist in any form, but which results merely from the "natural" growth in traffic-generating activity independent of network modification

Diverted, converted and shifted traffic represent redistributions of one kind or another of traffic which exists in the base year. Induced and natural traffic represent the generation of new traffic over the period of time between the base year and the horizon year defined by

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* This taxonomy is an amplification of that presented in Schmidt, R.E., and Campbell, M.E., Highway Traffic Estimation, The Eno Foundation, Saugatuck, Conn., 1956, pp. 4-5.

the analysis. Induced traffic refers to that component of new traffic which was caused in some sense by transportation network modification, while natural traffic refers to that other component of new traffic generation which is insensitive to network characteristics (policy variables). Natural traffic results from growth in traffic-generating activity which is more or less a "pure" demographic and/or economic phenomenon independent of transportation (e.g., non-migratory net population increase or expansion of plants at their base year locations). Induced traffic results from growth in traffic-generating activity for which network modification is at least conditionally responsible (e.g., the migration of households from rural to urban areas because of a sharp increase there in accessibility to employment opportunities, or the increase in output of a firm's plants in a region which derive reorganizational returns to scale because of reduced transportation costs).

The importance of capturing all five of these components becomes more critical as one considers larger investments, larger regions, and larger time spans. To date, no forecasting methodology of any transportation planning effort has captured this entire spectrum of responses to transportation change.* In general, this consistently "partial" approach has underestimated the dynamic growth of the underlying factors which create the demand for transportation.

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* Specifically, the "induced" component is almost totally ignored (see section E of this chapter).

Witness the fact that urban transportation studies have an embarrassing record of accomplishing little else than involving more vehicles on more highways at preplanning congestion levels.

## 2. Indirect Effects

A growing realization in contemporary planning of large-scale transportation investment is that such investment will not only affect system users (and operators), but will also propagate impacts throughout the transportation system's socioeconomic environment. Earlier studies have recognized that socioeconomic activity influences the demand for transportation. Accordingly, they forecasted measures of that activity prior to forecasting travel demand. This position is quite sensible, but it is insufficient, since those socioeconomic activity forecasts have been made without explicit consideration of hypothesized network change. Planners now recognize that socioeconomic activity and transportation are mutually causative and responsive.* The impacts of transportation upon socioeconomic activity are measured by a set of indirect effect variables. This section addresses the problem of identifying those indirect effect variables which are relevant to the evaluation of alternative plans.

The character of transportation investment's impact upon a region's socioeconomic activity was sketched briefly

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* Section D elaborates on this evolution of the transportation planning process.

in the earlier discussion of five types of traffic adjustment. In general, a sound public investment will in some sense accelerate a region's level of such activity. As implied in that earlier sketch, though, some subareas of that region will also be accelerated while the growth of other subareas will decline. The distribution of such an accelerative effect depends upon the location of the investment within the region and upon the competitive relationships between such subareas.

Transportation investment, like other forms of public investment, can increase a region's growth rate. Much more than any other form of public investment, however, investment in transportation systems has a high propensity to affect the spatial distribution of activities within the region, since it directly affects the relative competitive advantages of such subareas. Whatever type of indirect effects might be deemed relevant, it is of paramount interest to measure both the total regional intensity and the subareal distribution of those effects.

Regarding relevant types of impacts, a basic distinction typically is drawn between those relating to economic and to demographic activity. The former activity is concerned with all kinds of firms (and government enterprise), which produce, consume and distribute goods and services. The latter is concerned with a region's population. The two types are not mutually exclusive in the strict sense. It is the region's population which ultimately consumes goods and services and it is the region's population which supplies

labor. But the distinction is as convenient as any other.

A fairly standard set of intensity metrics has been established by recent studies for measuring economic and demographic activity. Employment is typically used to gauge the level of all intermediate industrial activity. Population, of course, is the primary demographic measure, and is often supplemented by personal income estimates. Finally, the relation of both types of activity to available land is typically captured by a set of "land use" measures, which express the proportion of land area devoted to each of several uses (e.g., residential, industrial, commercial, agricultural, public/semipublic, and others).

## D. Data Collection

No matter how sophisticated their techniques are, transportation planners can be no more effective than available information permits. Obviously, in order to develop a system of forecasting models, data on all variables involved in such models must be collected. Principles of data collection are principles of data collection, and an elaborate discourse on them is not the purpose of this section. There are a few basic issues in the transportation planning context, however, of which our methodological design must be aware.

In theory, the data collection task cannot really be separated from the scope-defining tasks of identifying relevant policy and effect variables nor from the task of

developing forecasting models. To decide a particular variable is not relevant is equivalent to deciding that data on that variable will not (or perhaps cannot) be procured. Regarding the theoretical interface between data collection and model-building, the following excerpt from a CONSAD Research Corporation report to the Northeast Corridor Transportation Project describes the ideal relationship quite succinctly:*

> Generally speaking, it has been the responsibility of the model analysts to initiate the specifications for data requirements. The task of obtaining relevant data for the models that are designed can best be described as an iterative process, wherein the model analysts must continually readjust portions of their models, and change their data specifications as the constraints of availability and resources come into play. It has been, and will continue to be, the responsibility of those in charge of data collection to make every attempt to minimize the number of such iterations, and similarly to see to it that the 'time lags' involved in each successive feedback to the analysts are reduced.

For most transportation studies, however, the data collection task is a massive, "all-at-once" undertaking, since existing data fall far short of minimum requirements. In this sense, data collection takes on the complexion of a discrete and separate task, although it becomes a continuous affair once a region is subjected to its first comprehensive transportation survey.

The cardinal rule in any empirical analysis oriented toward forecasting future events is to formulate a model(s)

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* CONSAD Research Corporation, Design for Impact Studies: Northeast Corridor Transportation Project, prepared for the U.S. Department of Commerce, August 1965, p. 8.1.

in terms of at least some parameters which remain constant over time. Ignoring problems of data availability, the straightforward approach for doing so would involve an empirical analysis of time-series data. That is, by referring to information accumulated for a number of historical time periods (e.g., past years), the analysis could determine directly any behavioral characteristics which have not changed over that sequence of time periods. The forecasting effort would be based on judicious assumptions regarding which of those characteristics (as captured by parameters) would most probably remain constant in the future.

The sorry state of data for transportation planning, however, has very little to offer for time-series analysis, particularly if relatively microscopic areal detail is desired (e.g., any areal unit finer than the county). The entirety of information required for comprehensive transportation planning may be classified simply into three sets:

(1) network description

(2) network utilization pattern

(3) socioeconomic and land use characteristics

The "network description," as defined in section B, represents the fundamental "independent variables" in the empirical analysis of Task 4. The "network utilization pattern" refers to direct effects, i.e., the equilibrium set of flows (and corresponding impedances) for all links and nodes in the abstract network, and summaries thereof (e.g., total origin-destination flows by each mode of transport). These utilization descriptions are "dependent variables" in the

empirical analysis, since they are characterized as a function of the network description or policy variables and socioeconomic and land use characteristics. This third category generally involves subareal values for the following variables: employment by industry group, population by personal income group, auto ownership statistics, and land acreage (or floor space) by type of use. In earlier studies, these measures were strictly independent variables which were used to estimate travel patterns (direct effects). As mentioned above more recent studies also analyze the dependence of socioeconomic and land use characteristics upon policy variables.

If any historical information at all on any of these three categories is available to a new study, such data generally will pertain only to socioeconomic and land use characteristics. Such information for individual areas has been used for public planning at least since World War II. But information describing the dyadic interactions between pairs of areal units was almost nonexistent before the inception of the origin-destination survey. Thus it is rare that any urban or regional study has time-series information on either of the first two categories at its disposal. Consequently, the development of forecasting models typically is based on a bank of "cross-sectional" data collected for one slice in time (the "base-year inventory"), and such data almost always are collected by a survey designed specifically for the given planning effort. With such data, it is of

course a much more difficult matter to identify parameters which remain constant over time. Whatever time-series information is available must be brought to bear upon the analysis. Most studies employ simple trending techniques, extrapolating aggregate time-series data on socioeconomic activity, to forecast total regional growth. Given this projection, they then employ cross-sectionally calibrated models to allocate that forecasted growth to subareas within the region and to estimate associated demand patterns. The necessity for such an allocative approach will receive elaboration below in section F.*

## E. The Evolution of Transportation Planning Methodology

The next task involves the development of analytical forecasting models and the estimation of their parameters through empirical study (i.e., "calibration" of the models). The total task involves two types of relationships: those which express direct effects as a function of transportation policy variables, and those which express indirect effect variables as a function of the policy variables. Several analytical models may be involved in each of the two "relationships."

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* For a comprehensive discourse on the value of cross-sectional versus longitudinal analyses, with specific reference to transportation, see Garrison, W.L. and Worrall, R.L., Monitoring Urban Travel, Final Report, Project 2-8, National Cooperative Highway Research Program, Northwestern University, August, 1966. For a general review of urban planners' information deficiencies, see Fergie, R.W., "Data for Urban Research," paper presented at the Joint Seminar on Urbanization, Australian National University, Canberra, May 1965.

Before launching into an elaborative discussion of methodology for developing such models, it will be helpful to consider first the manner in which the two basic types of relationships fit together. A convenient vehicle for establishing this integral viewpoint is a brief review of how forecasting methodology has evolved in transportation planning endeavors over the past decade. After said discussion, the next section will establish a framework for developing transport-sensitive models to forecast direct and indirect effects.

Comprehensive* transportation planning in the United States began in the early 1950's with the Detroit Metropolitan Traffic Study, which set off a wave of studies of passenger needs in various urban areas. Since that time, such planning efforts have been extended to regions within (or even crossing) state boundaries, and a few have even begun to focus on freight as well as passenger problems. Concurrent with this contextual transition, the profession has experienced a very significant evolution in planning methodology, significant in the sense that the sensitivity of forecasts to transportation policy variables has improved remarkably.

The transportation planning process as practiced in the mid-1950's involved the following strategy (see Figure II-1).** Measures of growth in socioeconomic activity

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* The term "comprehensive" here means an analytical effort waged with explicit reference to an entire network system, as opposed to just isolated elements thereof.

**This discussion refers only to the strategy by which models are applied for forecasting purposes (Task 6); it ignores that phase of planning which calibrates these models, to avoid confusion.

(e.g., population, employment, personal income) for the entire metropolitan area were first forecasted, based on a prorating of national trends or some other such projection strategy. These overall totals were then allocated to small subareas within the total region, by some strategy which was void of any explicit sensitivity to transportation.* This strategy was called a "land use model," since it determined land consumption associated with the socioeconomic activity forecasted for each subarea. Based on these land use forecasts, volumes of traffic origination and of traffic termination were then estimated by a "trip generation" model (see the following section).

Concurrently, existing utilization patterns were reviewed to identify major congestion problems, in reference to which planners would then specify alternative "skeleton" transportation systems for the future.** These skeletons were fashioned to cover a range of alternatives from a systemwide perspective; but they left considerable freedom for more detailed location and design decisions for isolated components of such skeletons.

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* In other words, past and current trends in the pattern of transportation investment were implicitly extrapolated into the future. For example, the metropolitan area control totals were allocated to subareas in some cases by prorating in proportion to base-year values of socioeconomic indicators.

**The existing system was always posed as one such alternative, primarily to identify congestion problems which would arise if future travel demand were provided no improvements in service whatsoever. This information assisted the "second-round" formulation of system alternatives (see next paragraph).

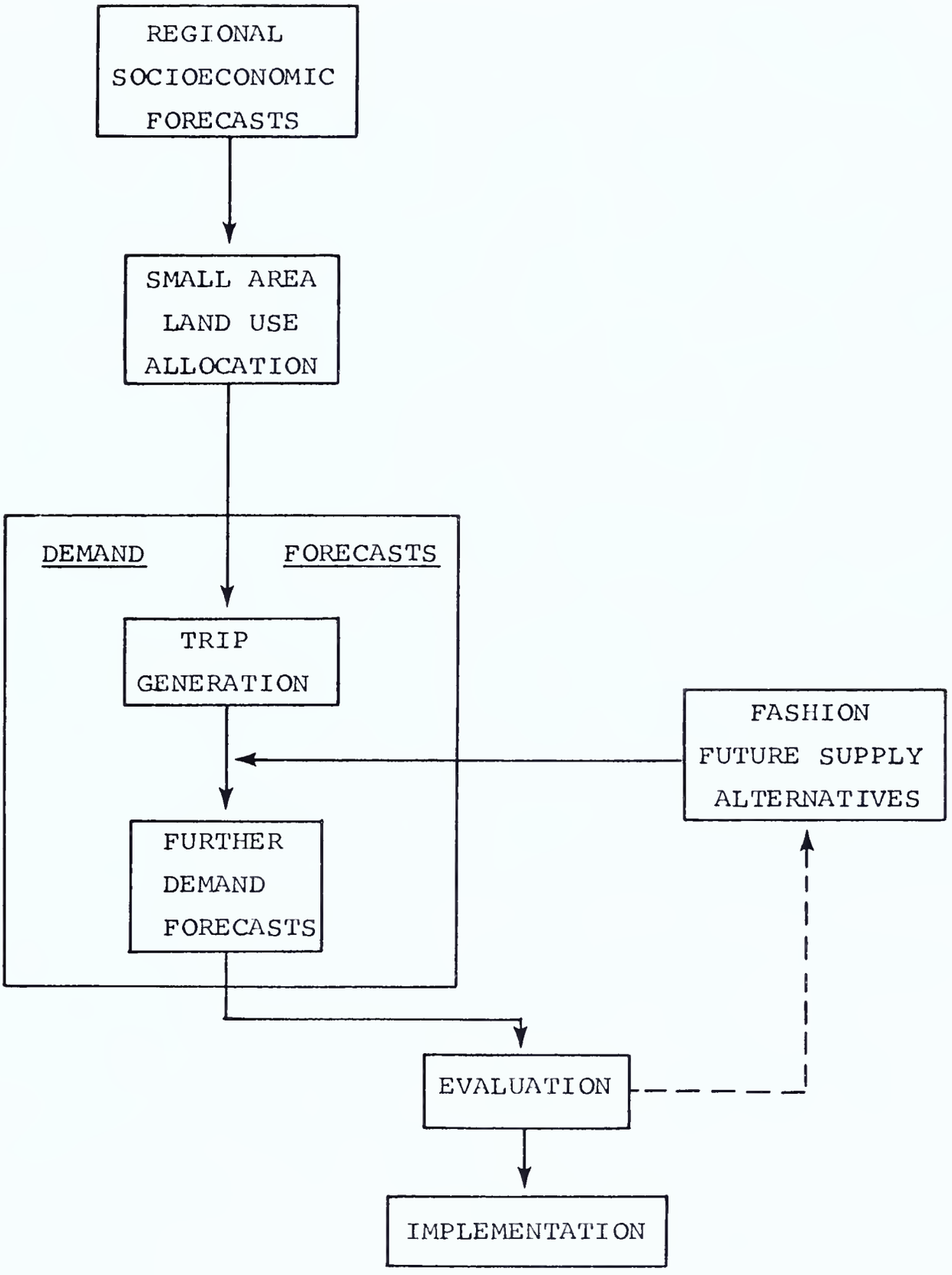


Figure II-1. Evolution of the Transportation Planning Process: First Stage

Given these skeleton specifications and the small area trip generation forecasts, demand forecasts were then made to estimate the equilibrium pattern of network utilization for each hypothesized skeleton. These demand forecasts were derived by a series of models which characterized direct effects as a function of hypothesized transportation policy variables and socioeconomic variables. Total transportation costs (i.e., strictly direct effects, plus capital costs) were then computed from these flow patterns, and a final recommendation was based on minimizing total transportation costs over this select subset of possible network systems. In some cases, the model system was used iteratively to generate further candidates for the region's future transportation system. Through this iterative strategy, these further candidates could be developed to accommodate anticipated patterns of future travel demand, as estimated for less refined alternatives in previous iterations. Finally, a program was designed for implementing specific projects in a time-priority schedule consistent with the chosen skeleton plan. In sum, minimization of total transportation costs was the unidimensional aim of such a planning process.

This perspective was eventually criticized for being too narrow, that is, for ignoring the hypothesis that transportation investment can influence the spatial distribution of socioeconomic activity. In response, a series of planning efforts evolved which proceeded roughly as

follows (see Figure II-2).* At the initiation of the planning effort, planners speculated on rather qualitative notions of future land use patterns which might be desirable for the region. They hypothesized several alternative land use patterns and then specified, on a very subjective basis, alternative skeleton networks which in their opinion would be compatible with any given land use pattern. The rest of the planning process remained unchanged; the same iterative strategy was employed to render the formulation of future transportation systems sensitive to anticipated travel demand patterns, and a least costly skeleton was recommended for each hypothesized land use pattern. Policy-makers were responsible for choosing a most desirable pattern. Thus, this sort of planning strategy encouraged decision-makers, at least implicitly, to assess tradeoffs between these two criteria of desired land use pattern and transportation cost minimization.

A logical extension of this strategy soon developed, and is depicted in Figure II-3. The strategy just described recognized the influential nature of transportation at one point in the process, namely, in the formulation of alternative systems. This third type of planning methodology incorporated transport sensitivity into the subareal land

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* The four-stage characterization given here is rather arbitrary; others might structure the literature differently from the manner portrayed in Figures II-2 and II-3. Nearly all would agree, however, that the evolutionary process indeed began with Figure II-1 and is currently leaning toward Figure II-4. The two intermediate stages presented here have been chosen primarily to ease the reader's comprehension of Figure II-4.

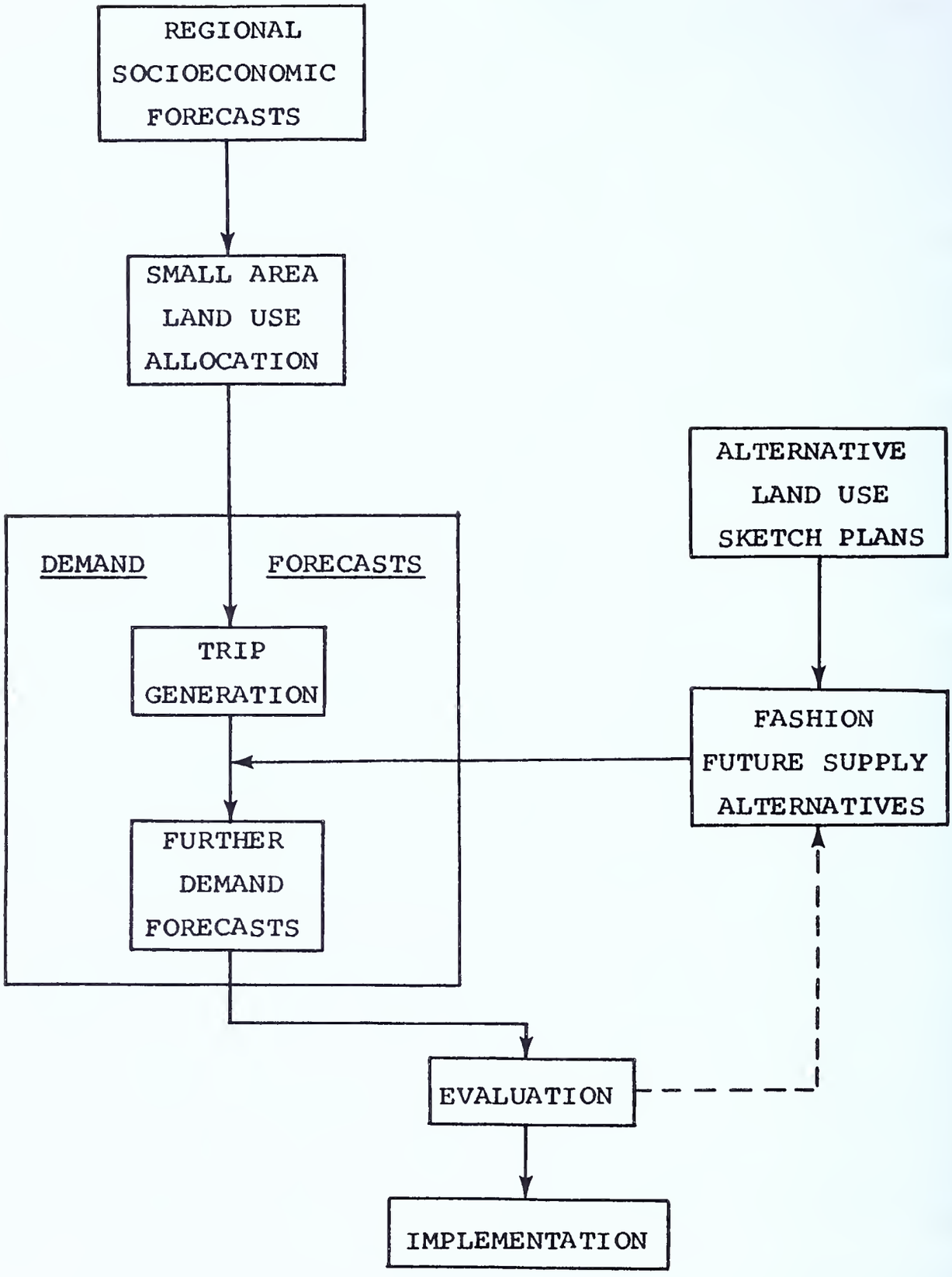


Figure II-2. Evolution of the Transportation Planning Process: Second Stage

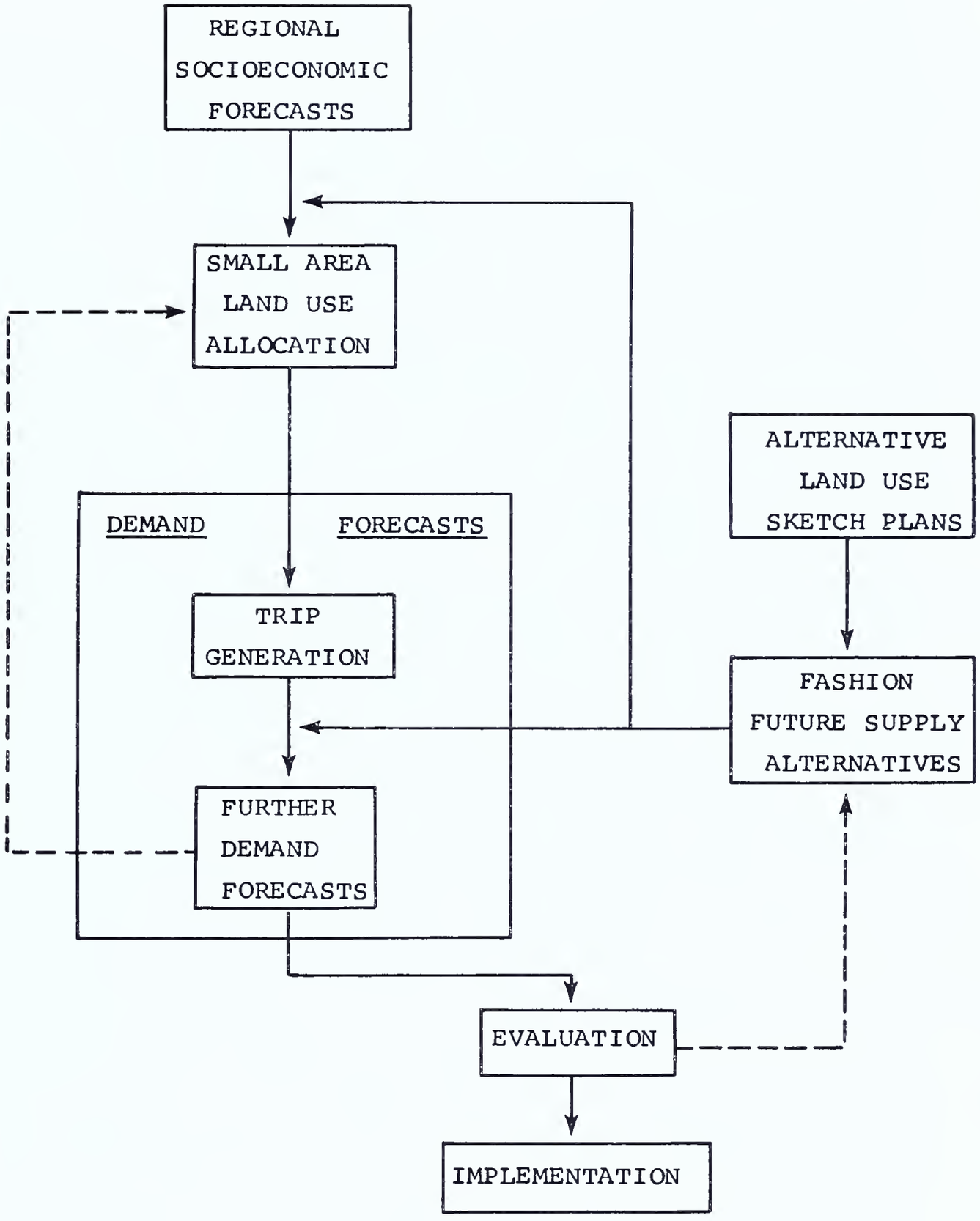


Figure II-3. Evolution of the Transportation Planning Process: Third Stage

use forecasts, which in turn gave more meaning to the demand forecasts. The land use allocation models were rendered sensitive to transportation by means of an "accessibility" variable, a moment-type measure which weights the socio-economic attractiveness of other subareas by the difficulty of traveling to that subarea (i.e., internodal impedance).* Moreover, since demand forecasts ultimately estimate the effects of capacity upon equilibrium impedance values, a feedback was provided from demand forecasts to the land use allocation model to reflect adjusted impedance values. Such transport-sensitive land use models have been given the term "impact models." These impact models characterized indirect effects as a function of transportation policy variables. Again, a dual criterion was implied in the evaluation stage, whereby a least costly skeleton system was recommended for each hypothesized land use pattern.

More recent planning efforts have involved a slight but very important amplification, namely, to feed the results of the land use allocation model directly to the "Evaluation" stage (Figure II-4). It gradually became evident that such estimates of impacts (indirect effects) were valuable information for decision-makers; that is, the consideration of larger and larger scales of transportation investment led to a consciousness of indirect effects, aroused to appreciable extent by particular pressure groups. With this introduction of the intensities and subareal distributions of various

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* See section F.

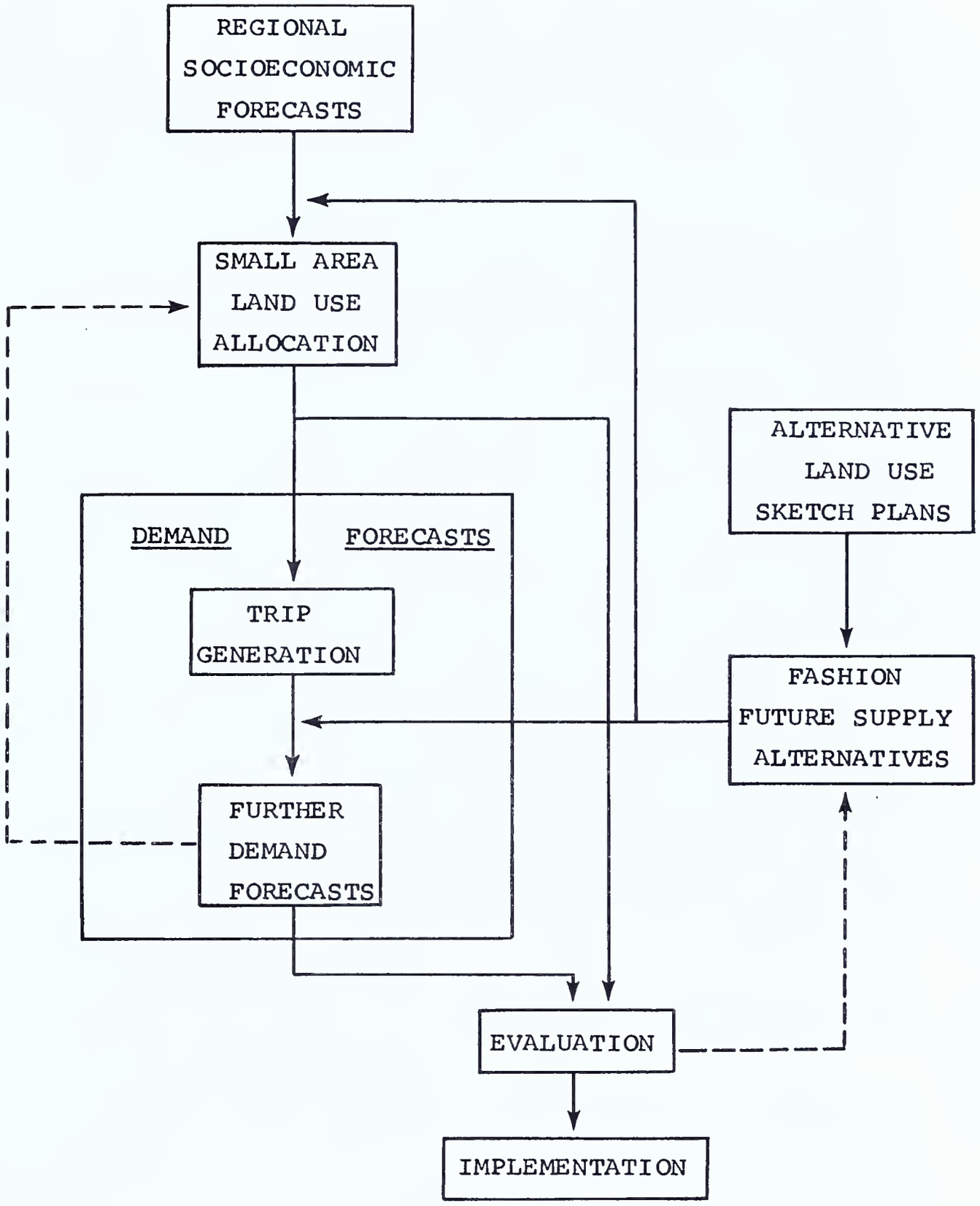


Figure II-4. Evolution of the Transportation Planning Process: Fourth Stage

socioeconomic measures, "goal" concepts broke down because of the multidimensional nature of the evaluation problem, and the planning process placed more emphasis on identifying and forecasting "all relevant consequences," with less emphasis on the narrow concept of minimizing total transportation costs. From a list of such forecasts, policy-makers were free to base their decisions on whatever subset of effect variables they might deem appropriate.

To summarize, two themes have pervaded this section. On the one hand, the manner in which the total forecasting model system was rendered more sensitive to transportation policy variables was emphasized, in order to set a context for the two general types of models to be discussed below: those which forecast direct effects and those which forecast indirect effects. A second theme referred to the evolution of the overall evaluation strategy in transportation planning studies. This matter will receive elaboration later in the chapter.

## F. The Forecasting Model System

Having clarified the context of models which provide transport-sensitive forecasts of direct and indirect effects, and having identified the interface between the two model types in a total forecasting model system, the individual components of that system will now be described in more detail. While indirect effects are forecasted prior to direct effects in that model system, the latter will be discussed first in this section since, because the impact

model concept is a relatively new development, the reader may be more familiar with demand models. As suggested in section D, the lack of time-series transportation data calls for an allocative approach; the reader will note that this "allocation" theme pervades the entire discussion of this section.

The response patterns of a region's socioeconomic activities and its corresponding users of a transportation system were characterized above in terms of five components of temporal traffic adjustment. No extant traffic forecasting methodology is conducted in such a manner as to identify explicitly these five fundamental types of temporal traffic adjustments, although a somewhat surrogate approach has been developed over the last decade by metropolitan passenger transportation planners. This approach is generally not waged with any explicit identification of the aforementioned components of traffic adjustment because it treats total future traffic in the aggregate rather than distinguishing between that traffic which existed during the base year and that which did not.

This point requires some clarification. By example, rather than making separate statements regarding (a) the "conversion" of existing traffic demand for a specific O-D pair from one mode to another, and (b) the manner in which the "new" traffic demand for that O-D pair allocates itself among available modes, this approach merely estimates the manner in which total future traffic (existing plus new)

allocates itself among available modes for that O-D pair. In general, the pattern of choice exhibited by base year traffic is abstracted and applied to total future traffic, a strategy which certainly stands on its own merits though it fails to identify the types of components listed above.

The metropolitan planning precedent, in its most popular form, consists of the sequential application of the following six types of analytical models (the first three have already received mention in the previous section):

(1) Regional socioeconomic forecasts - estimation of "control totals" for economic and demographic activity for the region

(2) Land use allocation model - allocation of regional totals for economic and demographic activity to analysis zones within the region

(3) Traffic generation model - estimation of total originated traffic and terminated traffic (i.e., measures of traffic outflow and inflow for each analysis zone)

(4) Traffic distribution model - allocation of each zone's originated traffic to specific destination zones (i.e., other analysis zones and the zone under consideration) and the allocation of each zone's terminated traffic to specific origin zones

(5) Modal split model - allocation of total O-D flows to individual modes serving each given O-D pair

(6) Traffic assignment model - allocation of mode-specific O-D flows to specific network links, superimposed for all O-D pairs to obtain total link flows.*

The general arrangement of these six models is illustrated in Figure II-5.

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* This discussion ignores the problem of multimodal journeys, but only for convenience in exposition. Some studies have considered multimodal route choice explicitly, but most have not.

## 1. Direct Effects

The shaded blocks in this figure represent the prediction of direct effects. The traffic generation model estimates "trip origins" and "trip destinations" for any given subarea I (or J) as a function of the socioeconomic characteristics of that subarea. The traffic distribution model estimates origin-destination flows as a function of $O_I$, $D_J$, and some aggregation of link impedances which measures a "representative" impedance for the O-D pair (note the feedback of link impedances from traffic assignment). Socioeconomic variables $E_I$ and $P_I$ are sometimes used to stratify the distribution forecasts. The modal split model allocates the total O-D flow ($Q_{IJ}$) among the modes connecting the two subareas I and J, using $E_I$, $P_I$ and impedance measures* as independent variables. The traffic assignment model forecasts route flows, using $Q^k_{IJ}$ and "capacity functions"** as input, typically by iterative application of a "minimum-path algorithm." Given these route flows for all origin-destination pairs, link flows and link impedances associated with the equilibrium pattern of link flows are determined.

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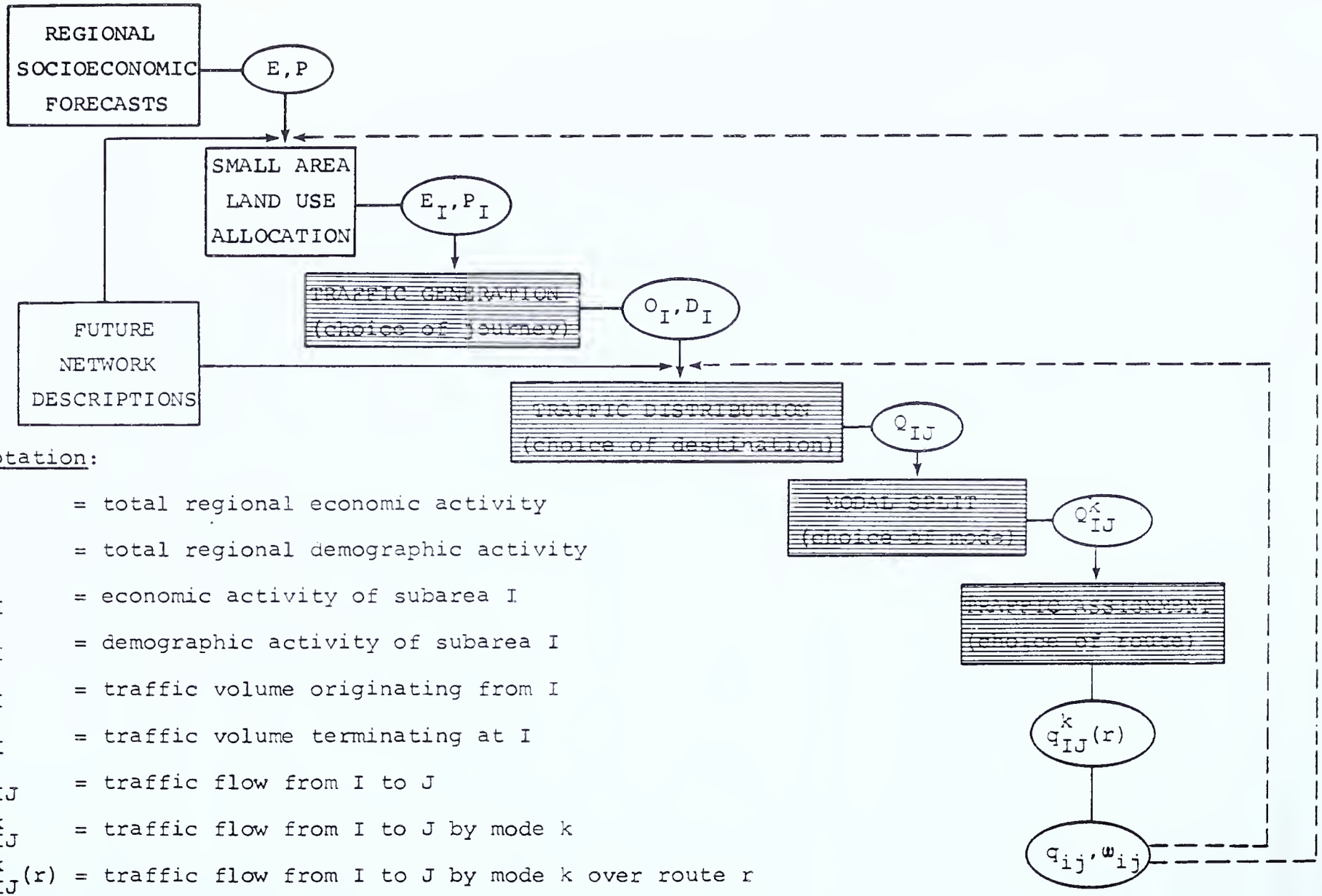
* Earlier studies placed modal split prior to the traffic distribution model, implicitly assuming that choice of mode was independent of either the destination or the intervening network. The sequence in Figure II-5 has come to be more popular.

**i.e., the mathematical relationships describing the manner in which average link impedance increases with link flow (due to congestion).




Notation:

E = total regional economic activity

P = total regional demographic activity

$E_I$ = economic activity of subarea I

$P_I$ = demographic activity of subarea I

$O_I$ = traffic volume originating from I

$D_I$ = traffic volume terminating at I

$Q_{IJ}$ = traffic flow from I to J

$Q^k_{IJ}$ = traffic flow from I to J by mode k

$q^k_{IJ}(r)$ = traffic flow from I to J by mode k over route r

$q_{ij}$ = total flow over link ij

$w_{ij}$ = impedance of link ij

Figure II-5. The Forecasting Model System in the Transportation Planning Process

The design behind this four-model approach has derived from the proposition that travel behavior -- given a fixed location for a firm or household -- involves four fundamental decisions: the choice of whether to journey, the choice of a destination, the choice of mode, and the choice of route. Most, if not all, transportation planners concede that these decisions are made much more simultaneously than the fourfold distinction suggests. However, for the areal detail typically used in transportation planning studies, a simultaneous model has been infeasible, and of theoretical interest only.*

The relationships between this modeling scheme and the five components of traffic adjustment are somewhat vague. In practically all studies the regional socioeconomic forecasts have been insensitive to network characteristics. This approach of course captures the "natural traffic" increase but, by strict definition, does not account for "induced traffic." Earlier studies moreover employed land use models which were also insensitive, thereby giving only a partial account even of "shifted traffic." Traffic generation analyses almost universally consist of regression equations whereby the allocated land use characteristics are transformed to "trip ends." Obviously, then, if neither induced nor shifted traffic is fully incorporated into the estimates of socioeconomic characteristics (and associated land use) prior to the traffic generation phase, then neither

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* See, e.g., Beckmann, M., McGuire, C.B., and Winsten, C.B., Studies in the Economics of Transportation, Yale University Press, New Haven, 1956, Chapters 2 and 3 (out of print).

component is wholly accounted for by the traffic generation forecasts.

The traffic distribution model deals explicitly with choice of destination (and implied choice of origin), thereby capturing competition over space for points of demand and supply and implicitly addressing the shifted traffic component, though only partially so long as the land use allocation model is insensitive to transportation. Modal split models deal explicitly with choice of mode, implicitly addressing the "converted traffic" component. Traffic assignment analysis treats the matter of route choice and thereby accounts implicitly for "diverted traffic." No phase of this methodology distinguishes between existing and new traffic in the sense outlined earlier. Furthermore, since each successive model in the sequence takes as fundamental input the output of the previous model, if no induction effect is accounted for by the outputs of traffic generation analysis, then the distribution, modal split, and traffic assignment models account for the choice patterns of existing plus <u>natural</u> traffic only.

Most recent regional planning studies, however, have adopted the position that forecasts of transportation demand will be in error so long as they are based only on a "natural law" of growth. A fundamental presumption of these studies is that the hypothesized network modifications will themselves have significant impact upon the locations and intensities of economic and residential activity. Thus, the allocation of land uses to analysis zones (and all

subsequent phases from traffic generation through traffic assignment) is designed to be transport-sensitive and, in at least one case,* the regional socioeconomic forecasts may also be rendered transport-sensitive. The former allows for a more complete and theoretically sound analysis of shifted traffic, while the latter offers better insight on induced traffic. The following subsection will elaborate on this matter of developing transport-sensitive land use models and regional socioeconomic forecasting models.

## 2. Indirect Effects

The above discussion pointed out that the extent to which the "shifted" and "induced" components of traffic adjustment are captured by demand forecasts depends on the extent to which they are reflected by the inputs to those forecasts. In other words, the degree to which demand forecasts account for these components depends upon the manner in which the regional socioeconomic forecasts and the land use allocation model are rendered sensitive to transportation network change. This subsection discusses methodological issues involved in developing models which characterize the regionwide intensity and intraregional distribution of socioeconomic activity as a function of transportation control variables.

In section C above, a distinction was drawn between two types of indirect effects: economic and demographic. This distinction is particularly convenient since it serves to

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* i.e., the Northeast Corridor Transportation Project.

differentiate between the two fundamental decision-making units in a free-enterprise society, namely, firms and households. The pattern of a region's socioeconomic activity as observed for any slice in time represents the aggregate effect of the choices of these individual decision-making units -- choices regarding intensity and location of activity. The ultimate purpose of models which relate indirect effect variables and transportation policy variables is to forecast some set of measures of the economic and demographic activity which will occur in each of the subareas or "analysis zones" within the region under study. For convenience in exposition, let these measures be defined merely as follows:

$E_I^v$ = the level of economic activity in industrial sector v in subarea I as of the horizon year

$P_I^s$ = the level of demographic activity of population group s in subarea I as of the horizon year

As a catalyst to the reader's understanding of the problem at hand, let us consider any arbitrary subarea I in geographic space, and let us identify those microscopic phenomena which would contribute, say, to an increase in that subarea's values of $E_I^v$ and $P_I^s$ from the base year to the horizon year. The former might increase because existing firms (in the "net" sense) increase their activity or because new firms (in the "net") sprout up, or both. Similarly, the demographic activity of this subarea might increase either because existing households increase their activity or because more people populate the subarea, or both. The problem at hand is concerned with the influence of transportation improvements upon each of these phenomena.

Let us first consider firms. In general, the typical industrial firm is to some degree sensitive to transportation. A given firm with a given geographical location faces the primary decision of how much to produce so as to maximize profit. That firm may be characterized by a "production function" which expresses the dependence of its output upon all of its inputs. Those inputs include land, labor, capital and all materials supplied by other firms. Another input is the total transportation cost incurred for shipment of material inputs from those other firms and/or for shipment of the firm's product(s) to markets. Transportation improvements which lower unit transportation costs for that firm permit it to expand its market, ceteris paribus. New firms not only face the output decision, but also must choose a location. In general, the location decision refers to two fundamental factors: (a) cost and quality of site; and (b) proximity to potential suppliers of inputs and to potential markets. Any meaningful perception of "proximity" will refer to time and/or cost of transportation rather than mere distance. Such is the general manner of transportation's influence upon existing and new firms.

Households, too, are amenable to such analysis, although their unit of output is not readily objectivized. While some concept such as "utiles of satisfaction" is probably most appropriate, it is convenient (but perhaps a bit rash) to measure the raw well-being of a living unit by its net personal income or some other such metric. Consider first a household of fixed size existing at some geographic location

during the base year. An increase in its net personal income might be due to a variety of factors such as wage or salary increases or the growth of children to working age. However, that net increase might also be derived through a lower unit cost of transportation involved in repetitive journeys to work, to shopping opportunities, etc. Indeed, some households' heads undoubtedly change jobs because of an easier "trip to work." Moreover, be it relatively infrequently, households do face the decision of choosing a place to live. Proximity to working, shopping and other activities is typically a relevant consideration along with cost and quality of site.*

The state-of-the-art in impact forecasting is characterized by a rather large gap between various and piecemeal theories of locational behavior on the one hand, and operational concepts of "social physics" on the other. The remainder of this subsection will review such operational concepts and the rationale behind them. As mentioned earlier, the currently most popular approach involves the sequential application of a regional socioeconomic forecasting model and a subareal land use allocation model, the latter being explicitly sensitive to transportation. The analytical context of these two models is depicted in Figure II-6.

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* For greater insight into the theory of location of firms and households, respectively, see Isard, W., Location and Space Economy, M.I.T. Press, Cambridge, 1956; and Alonso, W., Location and Land Use: Toward a General Theory of Land Rent, Harvard University Press, Cambridge, 1964.

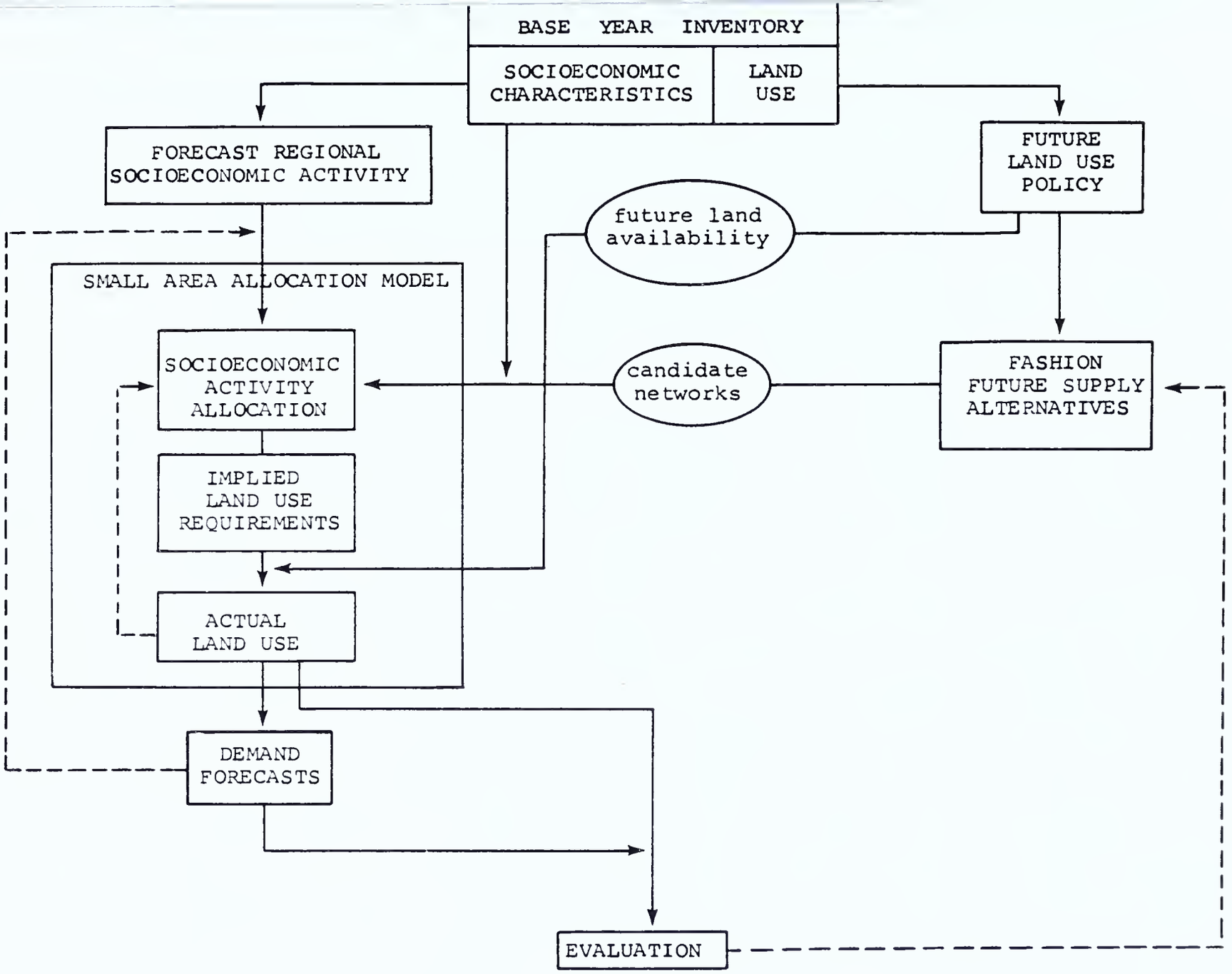


Figure II-6. The Analytical Context of "Land Use" Models in the Forecasting Model System

The most fundamental point to consider here, before going any further, is the reasoning behind the popular strategy of allocating regional control totals down to specific subareas. An impact forecasting strategy which is very descriptive of the behavioral patterns of firms and households would involve separate analytical models for each of these two decision-making units. Furthermore, it would probably involve somewhat different hypotheses for those decision-making units which have remained in a given subarea from the base year and those which are new to the subarea. Moreover, one would probably want to distinguish between those "new" units which relocated from some other subarea and those which were truly "new" in the growth sense. This sort of strategy would not only be capable of estimating the horizon year values of all $E_I^v$ and $P_I^s$, but would also predict specific migratory flows from one subarea to another. The data and computational requirements of such a model, generally speaking, would preclude its implementation.

Two simplifications are typically made to circumvent this implementation problem. First, just as was explained above for the traditional approach to demand analysis, most models treat total future economic (and demographic) activity in the aggregate rather than distinguishing between existing firms (households) and truly new firms (households). The second simplification is that most models typically refer merely to the net change in $E_I^v$ and $P_I^s$ for any subarea, rather than account explicitly for migratory movements. This

approach implicitly takes all activity in each subarea which is interested in relocating, aggregates such activity into one common "pool" of demand for land, and allocates it back to specific subareas on some transport-sensitive basis. This simplification, then, is one of the motives behind an allocative approach.

The allocative approach is convenient in another respect. While it is infeasible to develop an impact forecasting strategy which captures the details of behavior of various decision-making units in a manner which "grows" the entire region, that aggregate growth may be projected quite reliably by treating the entire region within its national context. Other things being equal, forecasting aggregate measures is more reliable than forecasting decomposed measures, since the scatter in data at a relatively microscopic level tends to balance out as those empirical observations are aggregated. Finally, it is also worth noting that the Federal government issues long-run projections of economic and demographic activity for the nation and its states which provide a convenient benchmark for regional socioeconomic forecasts.

Regional socioeconomic forecasting models typically have no sensitivity to transportation explicitly designed into them. In other words, it is assumed that the character of the contemplated investment in the region's transportation system will not be so large-scaled as to upset significantly the past and current trends in the region's service relative to the rest of the nation. A variety of such models have

been used, and are reviewed succinctly in a 1965 Bureau of Public Roads publication.* The concern of this discussion is more with the subareal land use allocation model.

All such land use models are rendered sensitive to transportation by means of a variable called "accessibility." This measure is designed to gauge the relative advantage any one subarea has over another in the "proximity to other activities" sense. Each subarea has such an accessibility index, which weights the attractiveness of all the region's subareas to the given subarea in inverse proportion to the difficulty of reaching each of the region's subareas. Defining the attractive power of subarea J by $Z_J$ and the average impedance encountered in traveling from I to J by $\omega_{IJ}$, the accessibility $A_I$ of subarea I to the entire region is given by the following moment-like measure:

$$A_I = \sum_J (Z_J/\omega_{IJ})$$

Other things being equal, economic and demographic activity tend to gravitate to the region's subareas in proportion to their $A_I$ values. This is the fundamental hypothesis of subareal land use allocation models, together with pre-specified constraints upon the supply of land. The major issue which affects the specific structure of any given model is the question of what activities any given activity prefers to be close to.

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* Meck, J.P., "The Role of Economic Studies in Urban Transportation Planning," U.S. Department of Commerce, Bureau of Public Roads, Washington, August 1965.

Such models generally differentiate households from industrial activity, of course, and they further subdivide the latter into several industrial groups which differ significantly in the activities to which they most prefer to be close. Lowry's model* uses a very simple scheme which adequately demonstrates the point of this discussion. He distinguishes "site-oriented" from "population-oriented" activity and calls them the "basic" and "retail" sectors respectively, for convenience in discourse. He characterizes the basic sector as follows:**

> [This sector includes] industrial, business and administrative establishments, whose clients are predominantly non-local. These "export" industries are relatively unconstrained in local site-selection by problems of access to local markets, and their employment levels are primarily dependent on events outside the local economy. Consequently, they have been treated as exogenous to the model, as activities whose locations and employment levels must be assumed as 'given.'

He defines the retail sector to include:

> ...those business, administrative and other establishments which deal predominantly and directly with the local residential population. Because these establishments have local clients, <u>site-selection is assumed to be powerfully constrained by problems of access to local residents</u>, and employment levels are assumed to be closely tied to local growth of population.

While it is assumed that the level of employment in the retail sector depends directly on the number of resident households,

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* Lowry, I.S., "A Model of Metropolis," Memorandum RM-4035-RC, The RAND Corporation, Santa Monica, August 1964.

**The next three quotes are taken from ibid., pp. 2-3; and underlining is added.

it is also hypothesized that:

> ...the number of resident households in turn depends upon the number of basic and retail jobs available at any given time. Furthermore, it is assumed that residential site-selection is powerfully influenced by the location of the resident's place of work.

The underlined portions of these definitions identify Lowry's hypotheses regarding "what activities prefer to be near what other activities." For both the retail and the household sectors, three types of equations are formulated: (a) an accessibility-based rule for allocating a regional control total for the given activity to subareas; (b) a balance condition which requires the sum of activity levels over all subareas to equal the regional control total; and (c) an inference regarding land consumption in each subarea. The allocation rules for retail employment and for households (i.e., population) are of the following general forms:

$$E_I = f\left(\sum_J cP_J/\omega_{IJ}\right)$$

$$P_I = f\left(\sum_J E_I/\omega_{IJ}\right)$$

Such is the general manner in which the accessibility concept is employed in most land use allocation models.

## G. Fashioning Alternative Transportation Plans

Once a satisfactory system of forecasting models has been developed, a study can then begin its efforts toward evolving attractive transportation plans for a region. As explained in section A of this chapter, these efforts involve a trial-and-retrial process which uses the forecasting model

system (or components thereof) iteratively to refine rather subjective "first notions" of what a region's transportation plan should be. Thus, it is somewhat artificial (but nevertheless convenient) to separate this fifth step in the planning process from the sixth and seventh, namely, the application of the forecasting model system and the evaluation of alternative candidates. The process of fashioning plans directly involves the latter two tasks.

The problem of fashioning alternative plans has been quite an enigma to proponents of the systems-analytic approach. Only a few studies have made significant attempts to objectivize the task, and these have only scratched the surface. Because of its crucial role in the entire planning effort, there is widespread agreement in the transportation planning profession that the plan formulation problem has high research priority. The lack of any concensus on methodology became embarrassingly evident in 1965 through an inquiry made by the Transportation Systems Evaluation Committee of the Highway Research Board:*

> [Each member] was asked to submit the five references that, in his opinion, represented the best published work dealing with the development of transportation system alternatives. Out of a number of references, only three appeared on more than one list.

Indeed, in a discussion of Ferguson's paper, John Hamburg portrayed the state-of-the-art quite succinctly:**

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* Ferguson, G.A., "Development of Transportation System Alternatives," in Highway Research Record No. 148, Highway Research Board, Washington (1966), p. 1 (bibliography included).

**Ibid., p. 6.

> A time honored technique is to get out the grease pencils and the aerial photo mosaic and begin drawing routes and systems.

Though it cannot be "solved" by analytical optimization techniques, the matter of choosing a "best" transportation system remains a constrained extremum problem, and definite insights arise from this point of view. The "optimal solution" to a particular problem, as the term is used in mathematical programming literature, is that alternative which satisfies the constraints of the problem while attaining the specified objectives to a degree that is as good or better than any other alternative. Any alternative which meets all of the constraints of the problem is a "feasible solution." Task 5 in the total planning process is concerned with generating feasible alternatives; Task 7 compares these feasible* alternatives in reference to some set of criteria.

In order that Task 7 be kept within manageable proportions, Task 5 cannot merely generate "feasible" solutions in gay abandon. While the main advantage of developing a set of forecasting models is that it permits many hypothesized systems to be tested without constructing them physically, the costs of applying those models increase linearly, more or less, with the number of candidate systems posed. Therefore, at least the more important evaluation criteria to be used in Task 7 must be brought to bear upon Task 5, to guide the delineation of a fairly small number of feasible alternative

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* Minimally, "feasibility" may be interpreted to mean a given alternative can be implemented within a specified budget constraint.

plans which cover a broad range of consequences. The Northeast Corridor Transportation Project, which is currently exploring a very comprehensive approach to the system formulation problem, is keenly aware of this need to consider objectives as well as feasibility:*

> The problem of alternatives selection at this initial stage is essentially one of delineating a relatively small number of prospective transportation systems from among a very large number of possibilities. Since transportation performance, cost, and regional impact will form the eventual basis of evaluation of each alternative, the initial selection procedure should be sensitive to these criteria, and should serve to integrate considerations of regional development patterns with the cost-service properties of the alternatives to be treated.

One very important question, then, is the selection of "most important" criteria to guide the evolution of candidate plans. Most studies confine their considerations in this task to criteria which refer only to direct effects. It is probably safe to say that they are generally guided by an objective of minimizing total transportation costs subject to the constraint that future travel demands must be matched reasonably by hypothesized system capacities (on an individual origin-destination basis). Some studies, such as the Northeast Corridor Transportation Project (see the previous quote), claim to consider regional socioeconomic development criteria as well as direct effects during this plan-fashioning process. But whether they really characterize

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* Northeast Corridor Transportation Project, "Study Design," op.cit., p. 11.

transportation directly as such a developmental instrument is quite dubious. Rather, they make preliminary forecasts of land use which are not sensitive to transportation change but which are tempered subjectively to reflect hypothesized alternative development patterns. The pattern of trip densities associated with any such future land use pattern, as estimated by a trip generation model, apparently is all that is explicitly "designed-to" in the plan formulation efforts of such studies. Thus, the criteria considered really are only direct effects (i.e., the projected travel demand pattern rather than development objectives per se).*

A number of analytical models have been developed which determine an optimal transportation network in one sense or another. However, their assumptions are far too oversimplifying to give them value over and above "rule-of-thumb" guidance. As an example, consider the optimum expressway spacing model developed by the Chicago Area Transportation Study.** Using a criterion of minimizing total transportation costs, this model determined the optimum mileage interval for a uniform grid of expressways to be

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* One planning effort which had proposed to view transportation largely as a regional development tool was that of the Appalachian Regional Commission. However, no attempt was made to capture this developmental function analytically. Research currently in progress at The Transportation Center at Northwestern University includes some investigation of this relationship between transportation and regional development, under the sponsorship of the Northeast Corridor Transportation Project; the results should be quite interesting.

**Chicago Area Transportation Study, Final Report, Volume III, op.cit., pp. 121.

superimposed upon a uniform grid of level and arterial streets in an unlimited region of uniform properties, assuming no prior construction of expressway facilities. The departures of such a model from reality are obvious. However, the technique gives some guidance to the planner's "grease pencil," be it awfully meager. Several linear programming formulations of the problem have been advanced,* but have yet to be proven feasible even for relatively uncomplicated networks. Wegmann** has developed and implemented a highway link improvement strategy based upon a multivariate analysis approach to functional classification. This approach will be given further description in the following chapter, since it was designed for a state highway network.

The previous pages have suggested that two types of criteria be considered, more or less, in sketching alternative plans: transportation demand and land development policies. All will admit, perhaps, that transportation influences both and therefore should be designed for both. Some of this previous discussion has implied rather innocently that demand and land use are taken as given, and the planning effort should derive a set of candidate transportation systems to meet these "givens." Yet any such candidate will

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* For examples, see Hay, G.A., Morlok, E.K. and Charnes, A., "Toward Optimal Planning of a Two-Mode Urban Transportation System: A Linear Programming Formulation," in Highway Research Record No. 148, op.cit., pp. 20-38, and works referenced therein.

**Wegmann, F.J., "Two Approaches Towards Functional Highway Classification Policy Decisions with Application to Southern Illinois," Ph.D. Dissertation, Department of Civil Engineering, Northwestern University, Evanston, June 1967.

alter those "givens" from their assumed values. Thus, this entire search process called "Task 5" is strictly a first-order approximation, to be refined upon applying the set of forecasting models and examining their estimates. Judicious iterations through that set of models can be a very enlightening strategy for fashioning alternatives.

Most studies have begun the task of fashioning alternative transportation systems by testing the existing network under projected demands. In other words, the entire modeling system is applied to a "no-change" alternative, at least to develop a crude estimate of anticipated desire-line patterns (O-D trajectories). This approach highlights glaring deficiencies, and thereby offers a convenient starting point for the determination of future transportation requirements. From this point, however, almost all studies have relied entirely upon planners' imaginations.

In most of these studies, hypothesizing the existing system with no modifications (or including any committed facilities) represents a first iteration through the entire modeling system. This gives a set of origin-destination demands (quite likely occasioning poor levels of service), which might serve as a basis for selecting a "first cut" of additional facilities. By continuing this iterative strategy through the entire set of forecasting models (or at least the distribution and assignment models), obtaining anticipated equilibrium O-D demands and making adjustments to supply after each cycle, several alternatives are converged upon. This approach can become quite cumbersome, since it can

involve a great number of runs through the model system, but it accounts for the fact that transportation "demand" is sensitive to transportation supply.

## H. Application of the Forecasting Model System

There is really very little commentary that need be made for the process of applying the set of forecasting models (Task 6); by far the more complicated problem is in designing and calibrating them. The fundamental difference, of course, between the calibration of models and the application of them for forecasting purposes is that whatever future values of inputs are known replace their base year values. Any input variables, for any model in the entire forecasting model system, that represent some measure of transportation service will take on new values specified exogenously, as given by Task 5. Furthermore, some input variables which are measures of socioeconomic activity will be changed, due ultimately to the regional socioeconomic forecasts which initiate the entire forecasting procedure. The procedure is applied in its entirety for each candidate transportation system hypothesized by Task 5.

One point of possible confusion is the distinction drawn in the last few pages between the iterative application of forecasting models <u>during</u> Task 5 and the application of the model system after Task 5 has been completed. Because of the time and expense involved in running the entire set of forecasting models, and because Task 5 aims only for a rather subjective delineation of different candidate networks,

the iterative strategy typically uses only the traffic distribution and assignment models. This limited approach, while it ignores (for the time being) the impacts of hypothesized plans upon land use patterns and associated trip densities, is considered to give a satisfactory "first-order" guidance of Task 5. When this iterative process, combined with planners' imaginations, eventually leads to a set of different plans which deserve full evaluation, then the entire forecasting model system is applied for each such candidate. These estimates of consequences (together with capital cost estimates) for each plan are then pondered, first by the planning staff and then by policy-makers.

One additional point which deserves brief mention is the matter of how the forecasting models might be applied to delineate the future time stream of effects. Some model systems are applied, for each hypothesized candidate, for each of several time intervals (roughly about 5-year periods) between the base year and the horizon year. In this manner a time profile of consequences is established; one advantage of doing so is that an incidence stratification by such time periods gives policy-makers more meaningful information as discussed in section C above.

Two additional considerations, moreover, might prompt such an incremental forecasting procedure. On the one hand, the planners might specify roughly a broad strategy for implementing parts of each "horizon year" candidate over time. An incremental forecasting procedure of course would cater

to such a specification, thereby rendering the estimated time stream of effects all the more meaningful.

The other consideration becomes relevant if dynamism is designed into the modeling system. Such a design would make the values of effect variables in some time period t depend on the values of control and effect variables in period (t-1) as well as the values of control variables in period t.* If a modeling system is not dynamic, then forecasts for each time interval could be made independently of each other. Dynamic systems, needless to say, are more desirable but ask a higher price for their implementation.

## I. Evaluation of Alternative Transportation Plans

In section A of this chapter, transportation planning was defined as "a process by which alternative strategies for modifying an existing network are evaluated in terms of the relevant consequences and capital costs associated with each such alternative." The general perspective taken in this evaluation of alternative strategies is exemplified by that of Wohl and Martin:**

> The principal use of economic analysis by highway and traffic engineers is to provide an approach to answering the fundamental question: Is the proposed project worthwhile and does it represent the 'best' project among those being considered?

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* Impact models sometimes are designed this way, based on the hypothesis that locational decisions tend to lag the transportation improvements which cause those decisions to be made.

**Wohl, M. and Martin, B.V., Traffic System Analysis for Engineers and Planners, McGraw-Hill, New York, 1967, p. 181.

> Stated in this fashion, it should be evident that our discussion will be restricted to mutually exclusive alternatives (i.e., while several alternative designs will be considered, including the null or do-nothing alternative, only one of the alternatives will be undertaken), and it will not extend to the more general situation involving selection of the best investment program or group of projects.

This approach is typically called "project analysis" (as distinguished from "program analysis," which involves the programming of interdependent projects) in benefit-cost theory.

As implied in the earlier definition of a "plan," metropolitan transportation studies typically view alternative horizon-year networks as mutually exclusive; those techniques which are traditionally associated with "project analysis" are applied to these alternatives. The staging of individual construction projects which are components of the recommended horizon year plan is generally treated very subjectively. For example, the Pittsburgh Area Transportation Study used the following rationale in dividing new construction among three time periods, each about six years long:*

> Generally, an urban freeway system should be built in the sequence that will maximize traffic service, alleviate the worst congestion problems, and best relate to land use planning. With typical urban growth patterns, it would appear that freeways should be developed progressively outward from key focal points, such as downtown. At the same time, sufficient cross-connectors should be built to avoid the possibility of dumping high traffic volumes into downtown. In principle the construction sequence would be: important radial routes and an inner-loop

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* Pittsburgh Area Transportation Study, Final Report, Volume 2: Forecasts and Plans, February 1963, p. 128.

distributor, then an intermediate loop, followed by remaining radial routes, and, finally, by an outer loop and other suburban connectors. By and large, this is an appropriate recommendation for this area.

The literature on project analysis points out three basic steps in the total evaluation process: (a) the identification of relevant benefits and costs; (b) the measurement thereof, for each alternative; and (c) the assignment of relative weights by which the various benefit and cost items can be placed on a commensurate scale. The first two steps have already been discussed as parts of earlier tasks in the planning process. Task 7, then, refers to the assignment of weights to the consequences associated with each plan and the subsequent comparative ranking of those plans.

The most popular approach to this task over the past fifteen years has involved an objective quantification of these weights, using the dollar as the commensurate unit. Dollar values for travel time and accident rates have been developed and applied so that these measures could be combined algebraically with estimates of capital and operating costs. Given this transformation, most studies have employed either an incremental benefit-cost ratio or a criterion of minimizing total transportation costs to rank alternative plans numerically. This sort of approach is convenient only where a few simple (direct) effect variables are involved.

Because of their apparently blind loyalty to such quantitative weights, these studies have aroused substantial criticism in recent years. An increasingly popular approach

is to specify maximum travel time constraints and minimize total monetary costs. The rationale for this strategy is quite reasonable:*

> Assumed costs of the time of travelers, while used in several other transportation studies, is not included here. The authors feel that the value of time is so dependent on the amount under consideration and the time of day, as well as the individual, that the concept of an average value is probably not particularly useful.

With either approach, the brunt of the evaluation task has been handled within the planning effort, and one final plan has been recommended to policy-makers for their approval.

As discussed earlier in section E, there is a growing conviction among planners that broader criteria should be considered in the evaluation process. For example, some recent studies have applied essentially the same approach as described above, but for each of several preconceived land use arrangements. Although at least one study** developed an ordinal ranking scheme for such a broader situation, with this approach the task of assigning weights generally is left to the subjective ponderings of policy-makers. The same strategy is applied where even more consequences, such as socioeconomic impacts, are considered. Regarding such cases, the concensus of the literature

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* Hay, G.A., Morlok, E.K. and Charnes, A., "Toward Optimal Planning...," op.cit., p. 21.

**Southeast Wisconsin Regional Planning Commission, Land Use - Transportation Study, Planning Report No. 7, Volume Two: Forecasts and Alternative Plans, 1990, Waukesha, June 1966.

appears to favor the use of numerical benefit-cost calculations to the extent possible, so that as much information as possible can be collapsed for straightforward assimilation by policy-makers; however, caution should always be exercised to minimize inclinations to ignore accompanying information on incommensurate and/or intangible effect variables.* Moreover, as discussed in section C, a liberal dose of taxonomy in preparing information displays for policy-makers is often advised.

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* Vogt-Ivers and Associates, Social and Community Value Factors, Ohio Procedure Manual #9, prepared for Ohio Department of Highways, 1966.

# III
# A GENERAL SURVEY OF STATE TRANSPORTATION PLANNING

The previous chapter presented an overview of the comprehensive transportation planning process which has become somewhat institutionalized by scores of metropolitan area studies. The next logical step toward designing a planning methodology for PennDOT is to establish the state-of-the-art of transportation planning at the state level generally and to review the specific planning strategy currently employed in the Commonwealth. This chapter gives a general survey of methodology that has been used by states, and indicates trends thereof as well as issues peculiar to the state level. This review supplements the perspective which the previous chapter has given to the Pennsylvania situation. In turn, chapter IV surveys in some detail the planning (and relevant research) strategies employed by Commonwealth agencies whose activities bear directly upon transportation investment decisions, thereby establishing a specific benchmark for our methodological design.

With only a few exceptions, transportation planning at the state level has been confined exclusively to the highway mode. Through the Federal-Aid (Hayden-Cartwright) Act of 1934, Congress authorized expenditures, not to exceed 1½% of the total federal-aid apportioned to each state, for making surveys, plans and engineering investigations of projects for future construction. From this legislation

there evolved a rather institutionalized series of "highway planning surveys" which currently remain a popular planning methodology of many state highway departments. These techniques lack any meaningful analysis of interdependencies between various highway links, and their emphasis is on planning to relieve the most pressing of currently observed problems. The first part of this chapter discusses this traditional methodology.

With the scheduled completion of the 41,000 mile National Interstate and Defense Highway System in 1972, however, more and more concern is being expressed for future statewide highway needs. The importance of planning individual facilities in the context of a state's entire highway network is receiving increasing recognition. The studies evolving from this changing perspective differ from their past generation counterparts by placing major emphasis on the application of metropolitan area transportation study techniques to estimate intercity travel demand. More and more states are conducting statewide origin-destination surveys and are applying traffic models that can predict future travel demands for a statewide network system. In at least two cases (Connecticut and California), moreover, a transportation planning methodology which considers non-highway modes on a systems-analytic basis has been developed. The latter parts of this chapter discuss all of these rather recent developments.

## A. The Highway Planning Surveys

Since the early 1940's, all state highway departments have conducted a periodic series of highway planning surveys to procure information for establishing future highway needs. This series includes (a) highway inventories, (b) road-life studies, (c) traffic surveys, (d) highway classification studies, (e) motor vehicle use studies and (f) fiscal studies. Data obtained from these surveys, together with projections of traffic flows, are used in a continuing study of highway needs which identifies and evaluates future projects of highest priority.

While there are many variations between individual state highway departments, elements of a generally accepted methodology have evolved from the highway planning surveys. The surveys themselves constitute a large part of the total highway planning process (this effort corresponds to Task 3 -- Data Collection -- in the sevenfold task structure described in the previous chapter). Highway inventories and road-life studies yield data on the physical characteristics of the existing highway plant, while traffic surveys measure the utilization of that plant. From this information, developed for each link in the entire state highway network, classification studies are conducted in order to break the highway system down into groups of facilities having similar characteristics. Supplemented by motor vehicle use studies which determine socioeconomic characteristics of road users as well as supplying information pertinent to delineating cost responsibilities, an assessment of needs is undertaken

by identifying existing deficiencies. Individual projects, based upon their relative urgencies, are proposed and evaluated by economic analysis, and the financing of these projects is investigated with the assistance of fiscal studies. Traffic forecasts are developed for individual projects, independently of each other, for the purposes of economic evaluation and facility design.

There are some fundamental similarities and some fundamental differences between this traditional approach and the sevenfold task structure presented in the previous chapter's discussion of metropolitan area transportation planning. While the methodology involved with the highway planning surveys is more loosely knit than that of the urban studies, it really involves the same sequence of tasks, but with several significant deviations. First, this highway planning process has been going on for some twenty or more years in most states, so that the selection of relevant policy and effect variables is not a discrete incident as it is in urban studies, where planning efforts are beginning "from scratch." Traditionally, state highway departments have been concerned primarily with the location and type (i.e., facility class) of improvements and new construction, so that the relevant policy variables are quite similar to those used in urban studies. The only difference in this respect is that the highway departments select from several types of highways, while the urban studies select from two or three modes. Relevant effects have been limited in most cases to impacts upon highway users, and often only to those

for which dollar values can be inferred. The economic evaluation of proposed projects, then, typically refers to such criteria as vehicle operating costs, travel time costs, accident costs, and construction and maintenance costs. Incremental benefit-cost ratios or rate-of-return methods, and other similar approaches, are applied to these cost estimates to reach project selection decisions.

Other significant differences between this methodology and the task structure defined in the previous chapter regard the notion of a "plan" and how the gathered information is analyzed to evolve that plan. The big difference is that the methodology built around the highway planning surveys does not consider the network as a system of interacting links. By means of selected volume counts (both with automatic counters and loadmeter stations), link flows are determined from the traffic surveys, without any trip information (e.g., origin, destination, route, purpose). This observed performance of each link, together with an assessment of its structural deterioration, is used to describe the deficiency of each link. The proposed "plan" which evolves from a needs study is essentially a ranked list of individual link improvements rather than systemwide geometric configurations of network improvements. Thus, the plan which evolves from this methodology is a piecemeal array of "sore spots" rather than an integrated system aimed at serving future demand. In the urban studies, an examination of existing system performance is typically used as an initial

point of departure for fashioning alternative systems through iterative applications of traffic forecasting models. In this highway planning methodology, however, the result of this examination of existing performance frequently is taken as the finalized plan. This result might be supplemented by intuitive considerations of route continuity, but little else is done in the way of posing refined alternatives. The needs study, then, may be interpreted as Task 5 of the seven-task structure, though it involves no iterative search process.

Given the ranked set of link improvements, forecasts of future traffic volumes are made for each project and economic analyses are conducted to evaluate them; these steps correspond to Tasks 6 and 7 in the previous chapter's framework. The approaches used for forecasting future link volumes have varied widely; in some cases mere judgment or graphical projections are used, while in others a gravimetric relationship between traffic volume and population indices, weighted by intervening distance, is favored. Economic evaluation purports to select the best projects from an engineering point of view. Each proposed project is first evaluated in terms of its own anticipated performance by a benefit-cost ratio or a rate-of-return figure. Those projects which receive favorable evaluation in this analysis are then subjected to a comparative evaluation using inter-project ratios or rates-of-return, and some cut-off point in the list of projects is determined to reflect a budget constraint. In all of this evaluative process, individual

projects for all practical purposes are viewed as members of a list on a sheet of paper rather than as members of a complicated network configuration.

## B. Statewide Highway Origin-Destination Studies

From the perspective which today's planning expertise offers, the highway planning surveys and the methodology by which they have been used are quite crude, as the previous discussion suggests. While the above discussion has been rather critical of this approach by today's standards, it should be emphasized that all of the state highway departments have supported quite a wealth of research into improved planning techniques, particularly for application in the urban areas for which those departments are responsible. The previous section has characterized the highway planning process as practiced popularly during the 1940's and 1950's. While many states continue to follow such a strategy (again, except for their urban areas), since the mid-1950's there have been more and more instances of states adopting for statewide analysis the kind of methodology which they helped to develop for their urban areas. The key step in this methodological transition involves conducting an origin-destination survey of existing travel patterns. With this type of information, techniques which treat a state highway network as a system of interdependent links become implementable. Today we find state highway departments right in the middle of this transition, using a mixture of the traditional highway planning surveys (whose data remain

relevant) and traffic models developed in urban areas. This section discusses the sort of strategy by which states appear to be utilizing a statewide origin-destination study for highway planning.

While the traditional highway planning surveys focused primarily on rural highways per the Hayden-Cartwright Act, both statewide motor vehicle use studies and cordon counts around urban areas revealed the need for extensive highway construction within cities. The Federal-Aid Highway Act of 1944 recognized this need and accordingly provided unprecedented funds for selected projects in urban areas, with a corresponding extension of the 1½% planning funds. For rural areas, it was believed that counts on individual links assessed adequately an existing pattern of traffic volumes. In contrast, in the peripheral areas of cities, the wide variety of trip purposes and trip lengths and the complexity of networks were believed to be too obscured by volume counts. The experience gained from the planning surveys prompted the Public Roads Administration (later the Bureau of Public Roads) to initiate a number of home interview surveys in 1944.

Owing to the efforts of John T. Lynch and others at the Bureau of Public Roads, a manual of Procedures for the Metropolitan Area Traffic Studies was published in 1946 and has served as a guide for the many urban transportation studies since. In contrast to simple link volume counts which only determine utilization of isolated facilities in a network, the home-interview origin-destination survey

permits determination of the total realized demand for transportation within a study area, the nature of that demand (e.g., temporal variations and purposes of travel), and its geographic configuration. When related to socio-economic characteristics at both origin and destination, this information can be used to develop procedures for estimating future travel patterns in a manner which considers the spatial competition of potential destinations for originating trips, and vice-versa. Such an approach therefore permits the analysis of network utilization patterns in terms of entire routes rather than mere investigation of isolated links.

The implementation of the origin-destination survey in urban areas, and the associated development of systems-analytic traffic models to take full advantage of such data, served to emphasize the piecemeal nature of traditional state highway planning methodology. This metropolitan planning precedent gained wide acceptance, spurred extensive research on diverse topics of travel behavior and land use, and by the early 1960's prompted planners to initiate a similar approach at the state level. Several notable state screenline studies were conducted then to interview drivers en route, since a home-interview approach would have been rather expensive for a statewide assessment of travel demand patterns. During the past ten years, multiple screenline O-D studies were conducted in Pennsylvania, North Carolina, Massachusetts, Connecticut, Arizona, Rhode Island, and in at least eight midwestern states involved in a cooperative venture called the Mississippi Valley Screenline

Study; other states quite probably are considering similar surveys.

The basic strategy of such studies typically is to delineate a set of screenlines across a state* and interview vehicles crossing these screenlines for the following kinds of information:

(a) vehicle type
(b) vehicle occupancy
(c) trip purpose
(d) trip origin and destination
(e) where vehicle was registered or garaged
(f) time of interview

These data are supplemented in most cases by information from external O-D surveys conducted in various urban areas.

Given such origin-destination information, the highway departments of such states have applied trip generation, distribution and traffic assignment models (see the previous chapter) in order to forecast future flows between pairs of individual zones** and to estimate how that future demand pattern would be allocated to the links of a future highway network. Since trip generation estimates require projections of socioeconomic activity by zone as input, this methodology generally includes a subareal socioeconomic forecast as well as the traffic models themselves. In almost all cases,

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* For example, screenlines in the Mississippi Valley Study were established across the participating states roughly at each degree of latitude and longitude.

**These zones are generally subdivisions of counties defined by some arbitrary coordinate system (e.g., Illinois coded its O-D data to a coordinate system defined by 1/10 degree latitude and longitude).

the development of these models and the use of them for providing forecasts have been accomplished by transportation consultants rather than being done "in-house."

Much like the urban studies, while this four-model methodology is common to practically all of the statewide studies, there are various differences between the specific mathematical forms each state has used for any given model. It is useful at this point merely to highlight the similarities among the individual states' approaches. Except for Connecticut, all subareal socioeconomic activity forecasts (sometimes called land use models) have been based upon some simple concept such as linear extrapolation of time-series data for each zone, so that the impact of future transportation investment upon the intensity and spatial distribution of economic and demographic activity is ignored.

Differences between states' traffic models, for the most part, are in the independent variables used to explain travel patterns. The stock of trip generation models, for example, involve such variables as population, motor vehicle registration, employment, total retail sales, retail land acreage and acreage of recreational open space. Without exception, simple or multiple regression analysis is employed to develop equations which estimate zonal trip productions and zonal trip attractions. The specific variables used in any case depend largely on data availability and the types of travel into which the total travel pattern is stratified. For example, four basic types of trips are often

identified as follows:

(a) trips with origin and destination within the state
(b) trips with origin within the state and destination outside the state
(c) trips with origin outside the state and destination inside the state
(d) trips with origin and destination outside the state

While some statewide studies use no breakout of travel by trip purpose, others do. For example, the Missouri study identified five such travel strata:*

(a) truck trips
(b) work trips
(c) vacation trips
(d) socio-recreational trips
(e) personal business trips

Table III-1 defines the socioeconomic variables used in the trip generation model of the Central Massachusetts Corridor Study.**

Trip distribution models used in statewide studies have less variation in the explanatory variables hypothesized, but there are some conceptual differences. All distribution models account for the tendency for interzonal trip volumes to be greater if the zones are major generators of traffic, and they account for the attenuation effect of distance upon users' propensities to travel. The most popular approach is the "gravity model," which has been applied so extensively

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* Turner, J.R., "Development of a State-Wide Traffic Model for Missouri," paper presented at 51st Annual Meeting of American Association of State Highway Officials, 1965.

**Edwards and Kelcey, Central Corridor Traffic Study, Boston, 1965.

| | | Registered Autos | Population | Total Labor Force | Total Employment | Education Employment | Service Employment | Retail, Eat-Drink Employment | Housing Units | Residential Land-Use, Acres | Retail, Eat-Drink, Land-Use, Acres | Education Land-Use, Acres |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Home to Work | Gen. | X | | X | | | | | | | | |
| | Attr. | | | | X | | | | | | | |
| Home to Personal Business | Gen. | X | | | | | | | X | | | |
| | Attr. | | | | | | X | | | | | |
| Home to School | Gen. | | X | | | | | | X | X | | |
| | Attr. | | | | | X | | | | | | |
| Home to Social Recreation | Gen. | X | X | | | | | | | | | |
| | Attr. | X | | | | | | X | | | X | X |
| Home to Shop | Gen. | X | | | | | | | | | | |
| | Attr. | | | | X | | | | | | X | |
| Truck: Work to Work | Gen. | | | | X | | | | | | | |
| | Attr. | | | | X | | | | | | | |
| Truck: Other | Gen. | | | | X | | | | | | | |
| | Attr. | | | | X | | | | | | | |

ble III-1. Socioeconomic Variables Used in Trip Generation Analysis, Central Massachusetts Corridor Study

in urban studies that the Bureau of Public Roads has developed a complete set of computer programs for this technique. This model's fundamental hypothesis is based on an analogy to Newton's Law of Gravitation, and may be expressed neatly in mathematical terms:

$$Q_{IJ} = k \frac{P_I \cdot A_J}{w_{IJ}^a}$$

That is, the flow ($Q_{IJ}$) between any two zones I and J is proportional to the product of zone I's productive force ($P_I$) and zone J's attractive force ($A_J$), and inversely proportional to some exponential function of the impedance involved in traveling between the two zones.*

Simple forms of this hypothesis occasionally were used even in the 1950's, in the context of the traditional highway planning survey methodology, for purposes of highway classification** and design***. Of the states which have conducted a statewide O-D survey, those which employ a trip generation model use that model's estimates of zonal trip origins and zonal trip destinations as the productive ($P_I$) and attractive ($A_J$) forces. Others bypass an explicit trip generation analysis by using socioeconomic variables as indices of these forces. Regarding interzonal impedance, some studies use

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* The operational form of the gravity model is actually more complicated than the description given here. See Hansen, W.G., "Evaluation of Gravity Model Trip Distribution Procedures," Highway Research Bulletin 347, Washington (1962).

** Mylroie, W.A., "Evaluation of Intercity Travel Desire," Highway Research Bulletin 119 (1956), pp. 69-94.

***See Schmidt, R.E. and Campbell, M.E., Highway Traffic Estimation, Eno Foundation, Saugatuck, Conn., 1956, p. 83.

average travel time while others use mere distance. Other conceptual approaches which have been taken to the distribution problem include the "intervening opportunities" model* and the "system theory" model.**

Like the gravity model, from the urban studies there evolved a popular approach to traffic assignment for which the Bureau of Public Roads has developed a series of computer programs. The purpose of a traffic assignment model is to simulate the route choice patterns of predetermined origin-destination flows and thereby determine total expected flows on each link in a network. Two somewhat different approaches to this problem have been incorporated as options in the BPR program package. One assigns traffic to one best existing route and one best future route, for each O-D pair, by reference to "diversion curves" which give percentage distributions for various travel time ratios between the two routes. The other assigns all traffic to one minimum path generated from the future network (the "all-or-nothing" method). Both methods, furthermore, may be applied iteratively with the use of link capacity restraints which adjust average travel times to reflect network loadings and their

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* See Leonard, H.J. and Delana, W.B., "A New Model for Distributing Short and Long Distance Travel," ASCE Conference Preprint 220, Minneapolis, 1965 (applied to the Central Massachusetts Corridor).

**Ellis, J.B. and VanDoren, C.S., "A Comparative Evaluation of Gravity and Systems Theory Models for Statewide Recreational Traffic Flows," paper presented at 12th U.S. Annual Meeting of the Regional Science Association, Philadelphia, November 1965.

congestion effect. Practically all states with an O-D study use the BPR package, and they generally use the all-or-nothing option, without capacity restraints.

It should be noted that no modal split model is included in this methodology. Although such a model is applied in most urban studies to estimate the relative usage of automobiles and public transit by passengers, the methodology relating to statewide origin-destination studies usually establishes auto-equivalents factors to express auto, bus and truck flows in terms of one common vehicular unit.

To recapitulate, more and more states are adopting a statewide O-D survey and are applying the sort of forecasting model system typical of the earlier urban studies (i.e., no transport-sensitivity in the forecasts of subareal socio-economic activity levels). As the previous chapter suggested, however, the tasks of collecting data and of developing and applying such a system of forecasting models are not all that is involved in a planning effort. In particular, the matter of how those models are used as a tool for system design and evaluation is a critical methodological issue. For the most part, future projects are suggested by local engineers, and those which appear to be most urgent are proposed together as a statewide plan. The direct effects of that plan are then forecasted and evaluated by the same concepts of engineering economy employed in the analysis of the traditional highway planning surveys. There is little evidence to indicate that these states are using

the forecasting model system iteratively to generate a meaningful choice of alternate plans like the most impressive metropolitan studies do.

One exception to this point is a research project at Northwestern University* sponsored by the Illinois Division of Highways, which developed an analytical scheme for generating alternative plans on a basis far more objective even than any of the strategies used by metropolitan area studies. This agency had already contracted a consultant who carried out the sort of methodology discussed above, although just one plan evolved from that study.** The supplementary research conducted by Wegmann fashioned several additional plans, though its primary value is its contribution of objectivity to the plan formulation problem as expressed through the concept of a highway classification study. One of the most serious problems in state highway planning has been the lack of a uniform set of standards by which all problem areas in a state highway network can be assessed impartially. Wegmann's approach to classification treats the outputs of a traffic assignment model (e.g., hypothesizing just the existing and committed network but assigning projected O-D flows), including link

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* Wegmann, F.J., "Two Approaches Toward Functional Highway Classification Policy Decisions with Application to Southern Illinois," Ph.D. Dissertation, Department of Civil Engineering, Northwestern University, Evanston, June 1967.

**Wilbur Smith and Associates, Preliminary Draft of Illinois Highway Needs Study - Intercity Traffic Projection, New Haven, April 1966.

volumes and their functional characteristics such as commercial vehicle composition and average trip length for each link flow. It then applies a multivariate statistical analysis to group all links into individual classes in a manner which maximizes the homogeneity of each class. The highway planner then assigns level of service standards to these groups, adjusts the grouping to ensure continuity of routes, and feeds this plan into the forecasting model system. The process is repeated iteratively to convergence, and alternative plans are generated by assigning different service standards to the model's groupings. In this manner, all links throughout the state are evaluated by the same objective metric, yet the planner is not denied his responsibility to exercise his intuition.

## C. Multimodal State Planning Methodology

While a popular trend toward the statewide O-D study is currently evident among many state highway departments, two states have developed rather sophisticated methodologies which, among other admirable attributes, consider all modes of transportation. The State of Connecticut, through its Connecticut Interregional Planning Program, has implemented a large part of its methodology in the past few years.* The State of California has had an independent contractor design a comprehensive system of forecasting

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* See Coleman, L.E., and Barnes, C.L., Jr., "Connecticut Inter-Regional Planning Program," paper presented at Yale Bureau of Highway Traffic, New Haven, undated.

models, but apparently the implementation of that design has yet to be initiated.*

The Connecticut Interregional Planning Program (CIPP) is a comprehensive statewide planning effort which coordinates the planning efforts of the Connecticut Development Commission, the Department of Agriculture and Natural Resources, and the Connecticut Highway Department. It represents a very unusual case of an inter-agency cooperative effort which does indeed integrate evaluation of land development policies with transportation policies:**

> The study, in outlined form, can be envisioned as consisting of five broad areas of study or concern. These are: 1. Identification of Statewide Goals and Objectives -- articulating just what does the State want to do and be. 2. Studies of Statewide Potential -- projecting the most likely rate of growth, the form this growth will take, and determining whether or not these can be altered. 3. Studies to determine the direction of population growth -- predicting which areas of the State will become urbanized in the years to come and the types of urban development that will occur. 4. Recreation and open space -- determining the future needs for and the type and best location for these facilities, and 5. Transportation -- projecting the future needs of the State with respect to transportation facilities of all modes, including rail, air, and water, as well as highways.

Figure III-1 is a reproduction of a block diagram from the above-cited reference which describes the total

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* North American Aviation, Inc., Los Angeles Division, California Integrated Transportation Study, Los Angeles, September, 1965.

**Coleman and Barnes, op.cit., p. 2.

methodology of CIPP. Note the vertical division of effort into the five topics just mentioned. Note also the several points at which policy-sensitivity is explicitly identified, and the very substantial survey work undertaken.

Practically all of the forecasting models in this very ambitious methodology have been developed and calibrated through empirical analysis. While much of this design draws upon well-tested techniques used in urban areas, some of its features are inventive in nature and are looked upon more as research projects than as production operations. These features will be given brief review here.

The CIPP study staff felt that "one of the weakest links in past studies has been the lack of adequate means for quantitatively measuring how well each alternative plan fulfills the stated goals and objectives." As a step toward establishing an adequate means, CIPP staff members are attempting to uncover explicit objectives. All statements on goals and objectives (including the Legislative Record, political party platforms, special reports prepared for the state, etc.) are being assembled, analyzed and summarized. Moreover, a one-percent sample of households have been interviewed on a "grass roots" basis to assess the perceptions and desires of the general public. Moreover, the climate within which the CIPP methodology was designed strongly encouraged dialogue between planners, policy-makers and specific pressure groups. Results of these analyses have not been published to date.

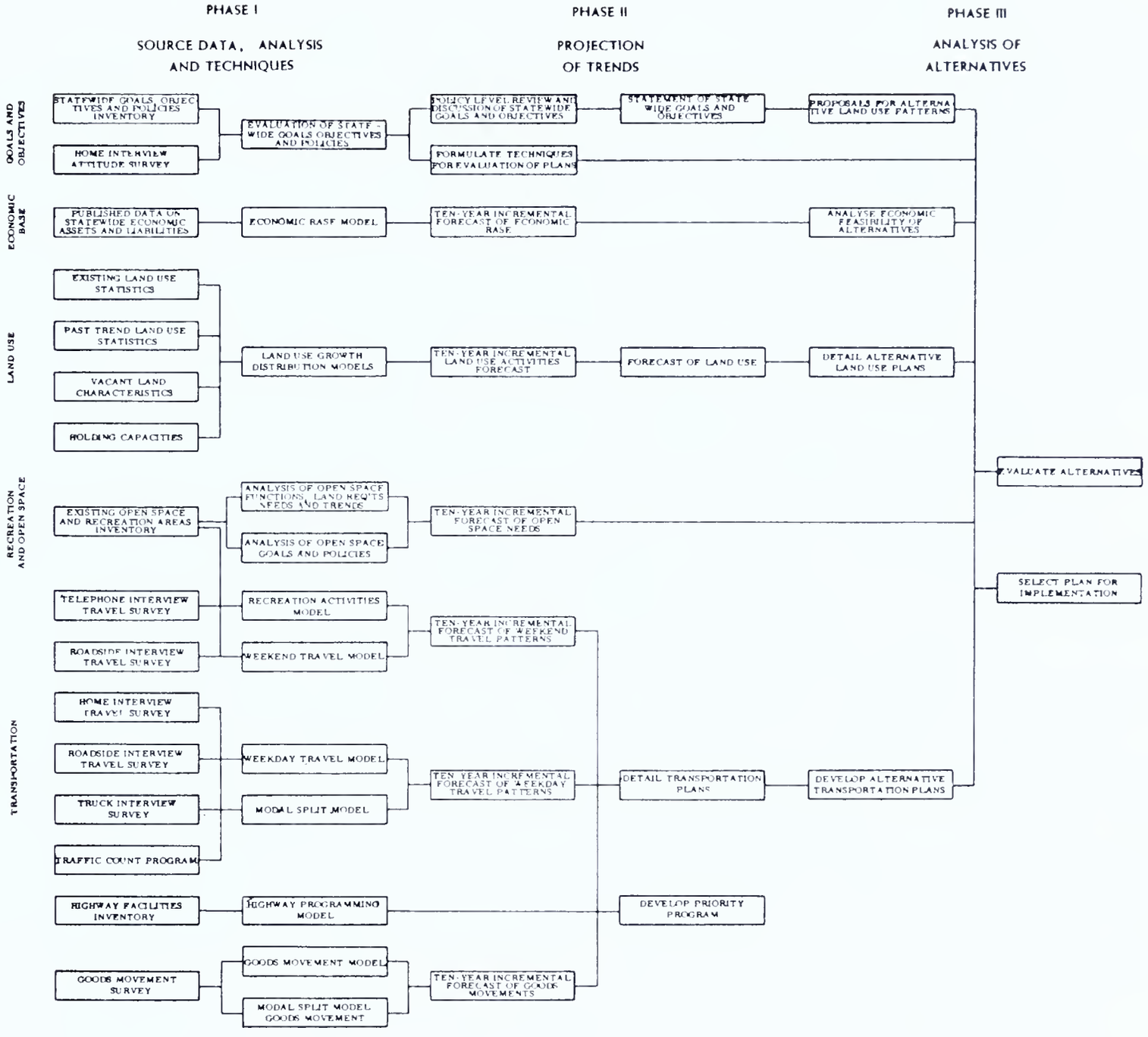
PHASE I
SOURCE DATA, ANALYSIS AND TECHNIQUES
PHASE II
PROJECTION OF TRENDS
PHASE III
ANALYSIS OF ALTERNATIVES
GOALS AND OBJECTIVES
ECONOMIC BASE
LAND USE
RECREATION AND OPEN SPACE
TRANSPORTATION
STATEWIDE GOALS, OBJECTIVES AND POLICIES INVENTORY
HOME INTERVIEW ATTITUDE SURVEY
EVALUATION OF STATE-WIDE GOALS OBJECTIVES AND POLICIES
POLICY LEVEL REVIEW AND DISCUSSION OF STATEWIDE GOALS AND OBJECTIVES
STATEMENT OF STATE WIDE GOALS AND OBJECTIVES
PROPOSALS FOR ALTERNATIVE LAND USE PATTERNS
FORMULATE TECHNIQUES FOR EVALUATION OF PLANS
PUBLISHED DATA ON STATEWIDE ECONOMIC ASSETS AND LIABILITIES
ECONOMIC BASE MODEL
TEN-YEAR INCREMENTAL FORECAST OF ECONOMIC BASE
ANALYSE ECONOMIC FEASIBILITY OF ALTERNATIVES
EXISTING LAND USE STATISTICS
PAST TREND LAND USE STATISTICS
VACANT LAND CHARACTERISTICS
HOLDING CAPACITIES
LAND USE GROWTH DISTRIBUTION MODELS
TEN-YEAR INCREMENTAL LAND USE ACTIVITIES FORECAST
FORECAST OF LAND USE
DETAIL ALTERNATIVE LAND USE PLANS
EVALUATE ALTERNATIVES
SELECT PLAN FOR IMPLEMENTATION
ANALYSIS OF OPEN SPACE FUNCTIONS, LAND REQUITS NEEDS AND TRENDS
EXISTING OPEN SPACE AND RECREATION AREAS INVENTORY
ANALYSIS OF OPEN SPACE GOALS AND POLICIES
TEN-YEAR INCREMENTAL FORECAST OF OPEN SPACE NEEDS
TELEPHONE INTERVIEW TRAVEL SURVEY
RECREATION ACTIVITIES MODEL
ROADSIDE INTERVIEW TRAVEL SURVEY
WEEKEND TRAVEL MODEL
TEN-YEAR INCREMENTAL FORECAST OF WEEKEND TRAVEL PATTERNS
HOME INTERVIEW TRAVEL SURVEY
ROADSIDE INTERVIEW TRAVEL SURVEY
TRUCK INTERVIEW SURVEY
TRAFFIC COUNT PROGRAM
WEEKDAY TRAVEL MODEL
MODAL SPLIT MODEL
TEN-YEAR INCREMENTAL FORECAST OF WEEKDAY TRAVEL PATTERNS
DETAIL TRANSPORTATION PLANS
DEVELOP ALTERNATIVE TRANSPORTATION PLANS
HIGHWAY FACILITIES INVENTORY
HIGHWAY PROGRAMMING MODEL
DEVELOP PRIORITY PROGRAM
GOODS MOVEMENT SURVEY
GOODS MOVEMENT MODEL
MODAL SPLIT MODEL GOODS MOVEMENT
TEN-YEAR INCREMENTAL FORECAST OF GOODS MOVEMENTS

Figure III-1. Block Diagram, Connecticut Interregional Planning Program

Like the forecasting model system typically used in urban areas, the Socioeconomic Growth (or Economic Base) studies are being used primarily to establish control totals for statewide population and employment (and vehicle ownership) for the various projection years (ten-year intervals through 2000). Without precedent, however, research is being conducted to try to capture the induction effect of public investment upon the state's socioeconomic growth.* Again, no results of this effort have been published. However, this point makes it clear that CIPP staff members are conscious that the traditional methodology of urban studies really ignores the induced component of traffic growth.

They are also aware that many metropolitan area studies yield only a partial estimate of "shifted traffic" (see the previous chapter), since those studies' estimates of land use (or the subareal distribution of socioeconomic acitivity) are insensitive to transportation and land use policy. Accordingly, an accessibility-based growth allocation model has been developed and calibrated;** the model contains explicit constraints upon zones' capacities for various land uses, as dictated by land use policy. Note the conviction here that transportation investment can affect

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* ibid., p. 6.

**Alan M. Voorhees & Associates, Inc., "A Model for Allocating Economic Activities into Subareas in a State," May 1966.

significantly the spatial distribution of growth within the state.

The efforts pertaining to the planning of recreation and open space are very much in tempo with the recent upsurge in systematic outdoor recreation planning. The strategy adopted by CIPP involves three important steps:*

(a) a scaling of future demand for outdoor recreation facilities;

(b) the development of alternative plans (size-location patterns) of recreation facilities for 1990 to meet this demand; and

(c) comparative evaluation of these alternative plans.

A set of two models -- the Recreation Activities Model and the Recreation Travel Model -- was formulated to assist this planning procedure. The former was designed to describe the per capita demand for outdoor recreation by five categories in the State and by "towns." The latter predicts the manner in which this demand would be allocated between towns of residence and outdoor recreation locations.

Regarding the forecasts of transportation demand for purposes other than recreation, the four-model approach (generation, distribution, modal split and -- for appropriate modes -- traffic assignment) was adopted for both passenger and freight analysis. The gravity model is being used for both types of movement, as is the all-or-nothing assignment model.

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* Alan M. Voorhees & Associates, Inc., "A Model Framework for Recreation Planning in Connecticut," June 1966.

The methodology designed for the State of California follows the same broad approach that CIPP has applied for its transportation planning efforts, except that its technique for forecasting state totals for socioeconomic activity is considerably more complex. The forecasting strategy (see Figure III-2) is initiated by a demographic model which, assuming future birth, death and migration rates, estimates the future population (and personal income) of the state.* This information is then input to an econometric model of the input-output variety (see section D), which projects future values of state economic activity by industry class, on the basis of interindustrial dependences in production processes. These control totals are then allocated to individual zones by means of an accessibility-oriented land use model. The transportation demand model involves trip generation and distribution (of the gravity type) procedures for both person travel and commodity flows, and the "transportation simulation" allocates these forecasted "desire vectors" to individual modes and links.

For all of its bulk, the California design does not go into appreciable detail regarding specific forms of these models. The emphasis is on model logic and leaves unsettled many issues about each model's structure, thereby hinting considerably more research. To the extent that

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* A 50-year forecasting period is suggested, with 5- to 10-year intervals.

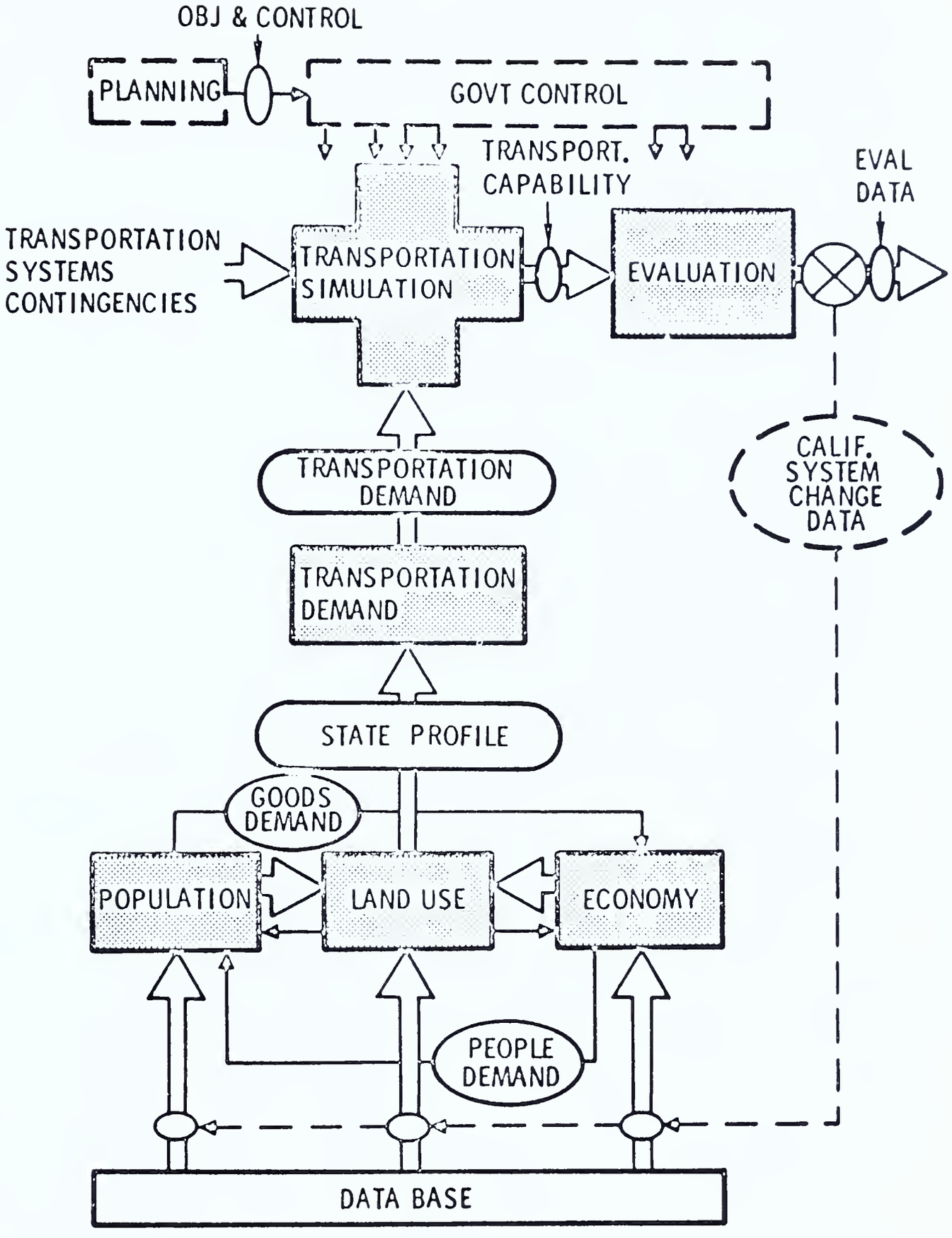


Figure III-2. The California Transportation Model

such structure is explored, the transportation demand and simulation models seem far less sophisticated than the state growth models and the land allocation model. Evidence of innocence with respect to the metropolitan planning precedent appears in many situations. For example, airline distances are mentioned repeatedly as the measure of interzonal impedance, yet this measure is totally insensitive to network changes. Another example is given by the suggestion that transportation demand in time period t be rendered dependent upon network characteristics in period (t-1). Yet no time lag relationships are mentioned in discussion of the land use model. As the previous chapter argued, it makes much more sense to use the time lag concept in the analysis of firms' and households' locational responses (land use), and makes less sense to have traffic flow patterns over a network in time t depend on the network's characteristics in time (t-1).

In summary, the important implications of the California study are few, pending implementation efforts. One point is quite significant; like Connecticut, this study incorporates transport-sensitivity into its land use forecasts. Another attribute worth noting is its well-informed advocation of interindustry input-output econometric models for projecting the state's economy into the future. By and large, however, the Connecticut effort has far more to offer for the purpose of this report, largely because it has implemented its forecasting model system and has documented its models in detail.

To summarize the chapter to this point, there is quite a mixture of sophistication prevalent today among the fifty states. Three distinct stages mark the evolution of state transportation planning: (a) the traditional highway planning surveys, (b) the statewide O-D study, and (c) the type of very comprehensive strategy exemplified by Connecticut, California and the Northeast Corridor Transportation Project (see the previous chapter). This last breed is unique in that all relevant modes of transport are considered and their forecasting model systems purport to capture the full impact of transportation investment upon socioeconomic growth. Pennsylvania, with its statewide O-D study and attendant methodology (see the following chapter), has been very much in tempo with the general trend in state planning methodology.

## D. State Econometric Models

Within the discipline of regional science a number of mathematical models have been developed to estimate the future socioeconomic activity of a region. These approaches, which fall under the general heading of "econometric models," include derivatives of economic base theory, central place theory, industrial complex analysis, and interindustry input-output techniques. All of these techniques purport to capture the structural interdependencies between various sectors of a region's economy. By such a systems-analytic approach, a study not only can gauge the direct impacts of public policy and/or population growth upon individual

industrial sectors, but also can trace the indirect multiplier effects which disseminate throughout the tightly woven economy. Of these techniques, the input-output approach is both the best-equipped and the most popularly used.*

This technique begins with a matrix of interindustrial transactions, and characterizes any given industrial sector's production function as a vector of "technical input coefficients." Any particular coefficient for that given industrial sector expresses the proportion of any particular industrial sector's product (in dollars) required for the given industrial sector to produce one unit (dollar) of output. In recent years, a variety of "interregional input-output" models have emerged which attempt to capture the sensitivity of industrial production patterns to locations and intensities of transportation system improvements.

Input-output econometric models of one variety or another have been developed for several states and/or subareas thereof. Such models have been implemented for the Pacific Northwest Region, New England, Maryland, Utah, Hawaii (Oahu) and California.** In none of these cases was

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* See Tiebout, C.M., "Regional and Interregional Input-Output Models: An Appraisal," The Southern Economic Journel, October 1957, pp. 140-147.

**This citation of California's input-output model refers to an earlier effort rather than to the North American Aviation study design mentioned in section C. See Hansen, W.L. and Tiebout, C., "An Intersectoral Flows Analysis of the California Economy," Review of Economics and Statistics, 1963.

the econometric model allied with any transportation planning effort. Only in two cases (the Northeast Corridor Transportation Project and the North American Aviation study for California) has an input-output model been designed as part of an integrated transportation study, and only the former has been implemented. In view of the tremendous flexibility of such a framework, particularly when rendered in terms of a transport-sensitive interregional concept, input-output models have much to offer for transportation planning of large regions.

# IV
# CURRENT PLANNING METHODOLOGY IN THE COMMONWEALTH

The previous chapter pointed out that the state-of-the-art of highway planning methodology in Pennsylvania is very much in tempo with most other forward-looking states. Indeed, it appears that only the state of Connecticut can claim to have implemented a transportation planning approach which is substantially more comprehensive and sophisticated than that practiced in the Commonwealth by its Department of Highways. This observation alone emphasizes the important "point-of-departure" role of this current methodology insofar as the purpose of this report is concerned, in terms of both analytical techniques and available data. It would be terribly naive to design a methodology which dismisses existing planning practices as irrelevant. Sophistication per se has no value except when its benefits are weighted against the costs of data procurement and model implementation. This chapter accordingly reviews current transportation (and related) planning methodology in the Commonwealth.

Emphasis should be placed immediately on the fact that, like almost all other states, elements of a coherently structured and at least partially objective transportation planning methodology in the Commonwealth exist only for the highway mode. Planning in its broadest sense suggests a prelude to decision-making, and the transportation decisions regularly made in Pennsylvania's government are of three types: investment, regulation and promotion. It is only

the investment decision, however, which offers a long-range connotation for planning, and such is the connotation which is central to the methodology proposed herein. While there are many agencies within the Commonwealth's government which deal with regulatory (and, less frequently, promotional) issues,* only the highway mode has involved regular investment decisions and the concomitant need for systemwide planning. Of course, a primary motive for the study reported herein is the expectation that public investment in non-highway facilities shall grow more prevalent than it has been in the past. However, for the reasons cited, this chapter discusses only the planning efforts of the Department of Highways and, where relevant, selected efforts of the Pennsylvania State Planning Board. Information on the latter's activity is relevant to the extent that one believes transportation and land use interact. As following chapters will testify, this report is based on a very strong conviction that this interaction must be considered.

At a time when almost all states were following the highway planning surveys encouraged by the Hayden-Cartwright Act of 1934, the Pennsylvania Department of Highways in 1957 chose to step far beyond this traditional approach by conducting one of the first statewide origin-destination surveys. This program involved nearly 300,000 roadside interviews at

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* See Wilbur Smith and Associates, Inventory and Adequacy of Existing Statewide Transportation Systems, preliminary draft of final report to Governor's Committee, New Haven, January 1968, chapter 9.

stations along nine screenlines within the state and along its boundaries.* While other states began to follow suit, in the face of dramatic highway travel increases the Department initiated a second O-D survey in 1962. This program included 500,000 interviews at 292 stations, including the original locations plus additional ones designed to inventory all highways serving at least 500 vehicles per day. Given this information on travel patterns, the Department's Bureau of Planning Statistics contracted the services of Edwards and Kelcey, Inc. to develop and apply a methodology for forecasting future travel patterns throughout the state.**

Concurrently with this research and development effort, the State Highway Commission was created in 1964 and was charged with fashioning a six-year highway system plan and to do so on an annual basis. The Commission was created out of two motives: to map in detail Governor Scranton's proposal for a ten-year, ten-billion dollar highway program, and to do so on a bipartisan basis. Until that time, the planning of Pennsylvania's highways had been done on a year-to-year basis. This move reflected a concern for the desires of the public and its pressure groups as well as

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* Green, M.K., "Multiple Screenline Study to Determine Statewide Traffic Patterns," Highway Research Board Bulletin 253 (1960), pp. 139-144.

**Edwards and Kelcey, Inc., Statewide Origin and Destination Study, prepared for Pennsylvania Department of Highways, Newark, July 1966.

for traditional engineering evaluation of projects, as evidenced by the Commission's operations:*

> The new Commission met extensively during 1964-65 to promulgate the initial Six-Year Highway Program, spanning the 1965-71 period. It held public hearings in each of the State's 11 highway districts, to gather opinion from citizens and local groups and governments on highway needs. These along with advance research studies prepared by the Department, provided the basis for the initial Six-Year plan. The Commission held another series of public hearings early in 1966, to be used as the basis for adding 1971-72 plans to keep the Six-Year plan six years ahead of current work. Similar hearings will be held annually, and the Department's advance planning agencies, in addition to their regular duties work throughout the year on preparation of statistics and projections for the Commission's use in mapping the long-range program.

These two steps in Pennsylvania's highway planning practices thereby touch upon all seven tasks discussed in chapter II. As yet, however, there is little evidence that the forecasting model system developed by Edwards and Kelcey will be used as a tool for evaluating the Commission's proposals. It rather appears that individual projects proposed by the Commission are evaluated by the Department's advance planning staff using traditional engineering economics techniques; that is, interactions between such projects in the context of a statewide network continue to be ignored.

The Department continues, however, to support research intended to refine the statewide study, and indeed is

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* "Your Highways Today," Biennial Report, Pennsylvania Department of Highways, June 1966, p. 6.

currently initiating a regional transportation planning methodology based on urban area techniques. Moreover, liaison with the State Planning Board has been increased, particularly on the matter of land use data. The Planning Board itself is initiating the development of "functional plans" for various types of public projects, and continues to map recommendations in conjunction with the Appalachian Regional Commission. All of these planning and research efforts discussed in the previous paragraphs will receive elaboration in this chapter.

## A. The Statewide Origin-Destination Study

The purpose of the Edwards and Kelcey study* was to forecast 1975 and 1990 highway corridor volumes based on expected levels of socioeconomic activity and highway corridor development per committed and proposed future facilities. As such, the study effort was confined to developing and calibrating a forecasting model system and applying it to one assumed highway plan; alternative plans were not formulated and tested. Like the earlier generation of urban studies, the resulting forecasting model system projected subareal values of socioeconomic activity without any sensitivity to transportation. Given these projections, the remaining forecasting methodology consisted of a trip generation, trip distribution and traffic assignment model.

A note on the abstract network used in this study is in order at this point. The 1962-63 O-D survey coded the

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* Edwards and Kelcey, Inc., op.cit.

locations of reported origins and destinations of the standard five-digit coordinate system utilized for all of the Department's highway studies (about 1750 grid units). Because its purpose was to forecast traffic flows for a network of highway "corridors" rather than to forecast design volumes for individual links, the Edwards and Kelcey study aggregated the data to a system of 149 zones (plus 14 "adjacent generator" zones depicting the state's immediate periphery and 19 more depicting the rest of the U.S.):*

> The primary zoning division was established along county boundaries with additional county subdivision carried out as a function of the location of significant population centers, to insure maximum conformance with the concept of the corridor spiderweb network and to also achieve a reasonable conversion of the coded survey trip origins and destinations. In general, zone size decreased with increasing population density. All intra-county zone limits coincided with political jurisdictions, or MCD [minor civil division] boundaries, existent within the county.

Two more points should be identified before going on to discuss the forecasting model system. First, any multiple screenline O-D study (as opposed to a home-interview approach) fails to sample travel patterns which do not involve crossing at least one screenline. The screenlines used in the survey delineated twelve "survey districts" in the state; all intradistrict travel went unsampled. As will be explained below, the Edwards and Kelcey study circumvented this problem by referring to travel data from eleven urban areas which

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* Edwards and Kelcey, Inc., op.cit., p. 8.

had been studied previously. The second point regards trip purpose information. Considering the total sample size and the granularity of the zone system, the consultants decided that a stratification of the analysis by trip purpose was statistically unjustifiable. The only distinction drawn in the study, then, was to separate passenger vehicle traffic from commercial vehicle traffic. Given these preliminaries, the remainder of this section discusses the forecasting model system used in the study.

That forecasting model system had five discrete elements, addressed in sequence as shown in Figure IV-1. The "state socioeconomic forecasts" established horizon-year* control totals of population and employment for Pennsylvania and surrounding states, relying largely upon projections made by federal planning agencies. The "zonal socioeconomic activity allocation" model distributed these state control totals to the traffic zones in two steps, both of which involved extensive use of prorating from state to county to zone areal units. The first step forecasted the zonal distribution of population and the second forecasted employment by zone; both population and employment were treated in the aggregate rather than breaking those variables down into different classes. The estimation of future travel patterns then followed, using the trip generation, distribution and

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* The entire model system was applied for two horizon years: 1975 and 1990. Only the strategy for the long-range horizon is discussed here, since it includes all of the issues involved in forecasting to 1975.

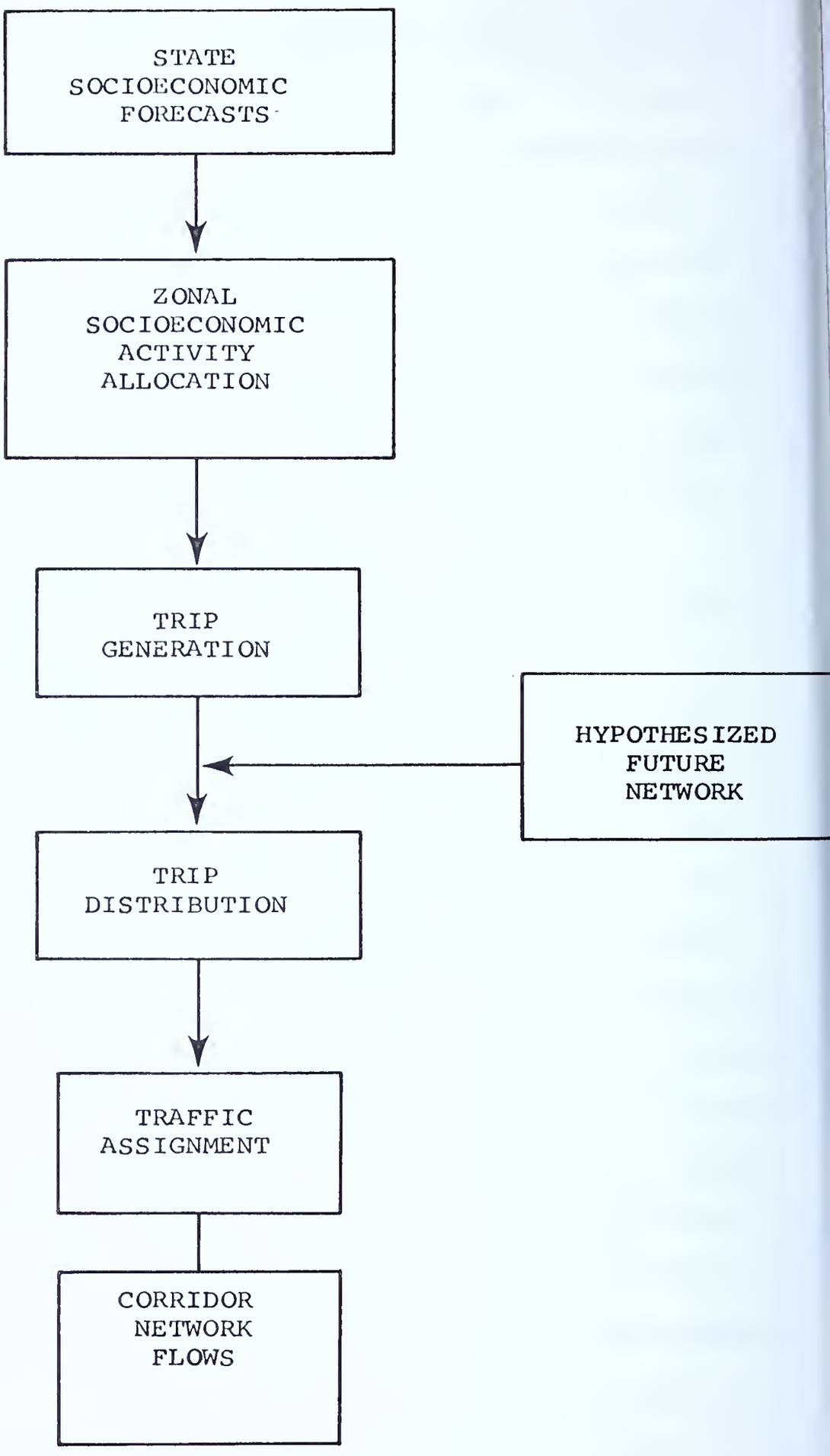


Figure IV-1. Major Steps in the Edwards and Kelcey Statewide O-D Study

assignment approach which is characteristic of urban area methodology. Each of these steps is given brief elaboration below.*

## 1. Socioeconomic Forecasts

The purpose of the socioeconomic forecasts was to project to 1990 those variables which most influence the trip-making propensities of each zone. In all, as many as five such variables were dealt with, depending on the type of zone under consideration (see Figure IV-2). The guts of this forecasting strategy, however, concentrated on projecting population by zone and then employment by zone; automobile ownership and number of housing units were later estimated according to their historical relationships with population and employment. The basic forecasts of population and employment were accomplished by prorating procedures which were used to "step-down" from state projections to county projections and then from county to zone projections. The forecasts of employment were preceded by the population forecasts, since zonal population was assumed to be a determinant of zonal labor force. In both, studies done at Temple University** were relied upon rather heavily.

The population model utilized the classic "component method" of demographic analysis, which identifies births,

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* For details of this model system and the calibration thereof, the reader is referred to the source documents.

**Temple University, Office of Research and Specialized Services, The Population of Pennsylvania: Projections to 1980, prepared for the Pennsylvania State Planning Board, June 1963.

| VARIABLE / AREAL UNIT | POPULATION | TOTAL EMPLOYMENT | AUTOMOBILE OWNERSHIP | HOUSING UNITS | LABOR FORCE |
|---|---|---|---|---|---|
| Traffic Zones in Pennsylvania (149) | X | X | X | X | X |
| Adjacent Generators (14) | X | X | X | X | |
| External Zones (19) | X | | | | |

Table IV-1. Socioeconomic Variables Forecasted to 1975 and 1990 by the Edwards and Kelcey Study, for Various Areal Units

deaths and net migration for each zone. The 1990 state control total for population was derived by interpolating between the Temple University forecast for 1990 and the Outdoor Recreation Resources Review Commission's forecasts for 2000.* The control total for Commonwealth employment in 1990 was obtained by extending Temple's 1980 projections, assuming a constant labor force participation rate from 1980 to 1990. These projections constitute the "state socioeconomic forecasts" depicted in Figure IV-1. From this point, the component demographic model was applied to estimate county and zone populations, and then the employment model was similarly applied.

The state total for population was allocated to counties merely by hand-fitting Temple's most reasonable projection from 1960 to 1980 (based upon time-series trends from 1940 through 1950 and 1960), extending these best curves for each county to 1990 and then balancing total growth for all counties with the state total. The final step from county values to zonal values introduced the consideration of component trends (i.e., in the rate of natural increase and the migration rate). Except for some judgmental tempering to reflect peculiar zone-to-county relationships, zonal migration rates were assumed to equal parent counties' rates, determined from 1950-1960 data, and

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* Outdoor Recreation Resources Review Commission, Projections to the Years 1976 and 2000: Economic Growth, Population, Labor Force and Leisure and Transportation, Study Report 23, Washington, 1962.

rates of natural increase were prorated down from the state level (based on Bureau of Census projections of natural increase rates). Thus, the population model involved a lot of prorating from federal estimates of the state's future characteristics down to counties and then to zones by a component analysis. Yet the procedure was given sufficient structure that judgmental assumptions about zone-to-county relationships, particularly for migration rates, could be identified explicitly in terms of model parameters. Data problems were not very trying ones, since the Bureau of the Census summarizes demographic statistics for minor civil divisions (which may be collapsed into traffic zones) every ten years.

The employment model was not so fortunately bestowed. Employment statistics (by place of work) are not recorded by a state or federal agency for such small areas and therefore had to be estimated, even for base-year values, using a range of sources.* Given the state projection for total employment as described above, 1990 values for each county's employed labor force (employment by place of residence) were derived by extending Temple's time-series plots past 1980 to 1990. Zonal values of employed labor force were then estimated by computing from the synthesized base-year data a given zone's proportion of employed labor force to population, computing the same fraction for the

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* Edwards and Kelcey, Inc., Socio-Economic Trends and Forecasts, Interim Report No. 2., Pennsylvania Statewide O & D Study, Newark, April 1965, p. M-30f.

parent county, and holding the ratio between these two fractions constant through 1990. Employed labor force was then converted to total employment for each zone by projecting zonal ratios of these two variables from the base-year to 1990.

The previous paragraphs have described the methodology which Edwards and Kelcey (and, by implication, the Temple studies) used to forecast 1990 population and total employment for zones within the Commonwealth. Two supplementary efforts have not been discussed. For these internal zones and for "adjacent generator" zones, automobile ownership and number of dwelling units were forecast based upon their simple relationships to population in the base-year. The population and employment forecasts for adjacent generator zones involved a simpler version of the methodology discussed above, and such forecasts for all other "external" zones were accomplished by mere proratings applied to federal agencies' estimates of future socioeconomic activity for states.

This forecasting methodology, like any strategy which relies heavily upon simple projections of temporal trends, is weak in that it lacks any sense of behavioral causality. Of course, considering the amount of effort required to synthesize zonal employment data, and considering the convenience of utilizing the Temple forecasts (which use nothing but time as an objective explanatory variable, incidentally), this "first cut" at zonal socioeconomic projections appears to be quite an effective approach.

Nevertheless, several key shortcomings should be pointed out here. One objection is that, without any specific information on individual zones' trends in such parameters as rates of natural increase and intrazonal work trips, the validity of any approach other than simple prorating of total population and total employment may be questioned. However, this point is really a criticism of inadequate data, and the subjective tenor of the Edwards and Kelcey forecasts can hardly be attacked in view of this inadequacy. Two further points, however, must be taken quite seriously. First, the assumption that employment opportunities locate in response to population is implicit to the methodology; but locational decisions of firms (and households) obviously are much more complicated. Interindustrial interdependencies have been ignored completely by working only with total employment, even though employment data are available by major industrial class at the county level. More importantly, however, no sensitivity to transportation policy is captured, although the final report clearly acknowledges the potential impact which transportation (through increased accessibility) can have upon population and employment patterns. Of course, these criticisms are advanced in full awareness that the Edwards and Kelcey effort constituted a very impressive piece of work, considering its purpose and its budget.

## 2. Trip Generation

The purpose of a trip generation model is to assess the travel propensities of each zone, in terms of future

trip productions (origins) and attractions (terminations), as a function of the zone's projected socioeconomic characteristics. As explained earlier, the statewide O-D survey did not measure intradistrict travel at all, yet these trips are an important component of each zone's total travel propensity. Fortunately, Pennsylvania is well-gifted with urban area studies, including thirteen cities at the time of the statewide study. Based on the unavoidable assumption that the external trip generation data from these cities was representative of the universe sampled by the O-D survey, such data formed the basis for all trip generation analysis. The absence of rural, low density sites in the available data was a recognized limitation, but by its very nature, information of this type would require field survey work.

The trip generation model involved six separate equations, derived through linear regression analysis; trip production and attraction equations were established for each of three vehicle types (auto, light truck and heavy truck). Vehicle ownership and population, expressed as densities per unit of gross land area, were used to predict trip productions; population and employment, also weighted by zone area, were used to predict trip attractions. This approach is quite conventional in statewide generation analysis. The only significant departure from convention involved a subsequent factoring of all trip generation estimates, based on county flow map data, which served to correct the model's tendency to underestimate

travel propensities of rural zones. Finally, based upon license plate information recorded at the border survey stations, the forecasted trips for all zones were factored down so that they included only internal trips.* This overall strategy, of course, resulted from a rather thorough empirical analysis.

### 3. Trip Distribution

Given that zones will generate a number of trips based on their socioeconomic characteristics, as forecasted by the trip generation model, the next question to be addressed is how will these trips be distributed between zones? In other words, the next problem is to forecast future origin-destination flows, classically termed the "trip distribution" problem. While most transportation planning studies have used the "gravity model" (see chapter III) for this purpose, Edwards and Kelcey adopted another popular approach known as the "intervening opportunities" model. This technique has a substantive theoretical base which the gravity model lacks, and if properly applied can perform as well as the gravity model. The very popular use of the gravity model, quite frankly, may be attributed largely to inertia rather than to conceptual reasons.**

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* "As all external traffic...had been completely surveyed at interview stations along the State boundaries, trip simulation procedures were required of the internal study area only." Edwards and Kelcey, Statewide Origin and Destination Study, op.cit., p. 23.

**For a thorough discussion of both models, see Heanue, K.E. and Pyers, C.E., "A Comparative Evaluation of Trip Distribution Procedures," Highway Research Record 114, Washington (1966), pp. 20-45.

Like the gravity model, the intervening opportunities model characterizes two opposing forces thrust upon the traveler: the relative attractiveness of each potential destination and the resistance offered by the transportation network leading to each such terminal opportunity from a given origin. The latter force, however, is refashioned in a positive sense, whereby the effect of spatial separation is expressed in terms of the cumulative destination opportunities within any span of travel time or distance from the origin. The theoretical support of this model is valid only for travel which involves a realistic choice of destination opportunities (e.g., it loses its theoretical appeal when applied to forecast trips from home to work). For predicting aggregate travel patterns, however, it is quite competitive with the gravity model. The Bureau of Public Roads has developed a computer package for this model, which Edwards and Kelcey apparently used.

Only two points need to be mentioned in relation to the consultant's use of this model. First, trips were stratified on two bases. The auto and light truck trips forecasted by the trip generation model were aggregated into "passenger vehicles," and this stratum was treated independently from the "commercial vehicles" stratum. Also, within each of these two strata, a distinction was drawn between short trips and long trips after preliminary empirical analysis (this strategy is typical of prior applications of the opportunity model). The second point refers to the fact that the survey data generally included

travel between survey districts, but not those trips which occurred entirely within a district. Yet the trip generation forecasts for each zone include both components of interzonal travel. This discrepancy was resolved by reference to a BPR motor vehicle use study,* which indicated that about 75% of all travel may be assumed to be of interzonal character. The distribution model thereby was applied to forecast total interzonal traffic flow.

### 4. Traffic Assignment

Given a projected matrix of origin-destination patterns, the remaining problem addressed by most transportation studies is how that traffic will utilize the projected network. Such is the purpose of a traffic assignment model, which takes an O-D pattern and produces a set of link volumes by applying some sort of "least resistance" hypothesis about user route choice. This type of model is included in the BPR computer package used by Edwards and Kelcey, and they did run assignments for a hypothesized future (corridor) network. It appears that they chose the "all-or-nothing" option discussed in the previous chapter, and used no analytical form of link capacity restraints. The results of this step yielded expected highway corridor volumes for the horizon year, per the primary objective of their study. As a final note, the function of these results is one of planning rather

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* "Motor-Vehicle Travel Estimates," Public Roads, April 1965.

than specific facility design:*

> The networks used for assignment represent the general highway corridors of the State and not necessarily all existing highways and roads. However, many of the links can be related to major highways and a number of significant travel factors are provided by the assignment of inter-zonal traffic to that system.

## B. More Recent Developments in Highway Planning Methodology

Since the completion of the Edwards and Kelcey study, the Department of Highways has continued to consider additional improvements in planning methodology. This further initiative has become evident on three major fronts. One has to do with local urban area studies, a second has resulted in a research contract let to Villanova University to improve upon the completed statewide study, and the third regards the evolution of a novel regional transportation planning strategy. These activities are reviewed in the following paragraphs.

### 1. Urban Studies

Prompted by the Federal-Aid Highway Act of 1962, which declared that urban areas with population greater than 50,000 must support its proposals for federally-aided highway projects with evidence of a continuing comprehensive transportation planning process, such studies for thirteen urban areas in the Commonwealth have been initiated. These local

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* Edwards and Kelcey, Inc., Statewide Origin and Destination Study, op.cit., p. 33.

planning activities have been sponsored by the Department of Highways in cooperation with the Department of Community Affairs and interested federal agencies. The typical methodology employed by these studies has been similar to that described above for the statewide study, with a rather weak scheme for forecasting socioeconomic activity followed by trip generation, distribution and assignment models. Almost no innovative technique has evolved from these studies; indeed, like so many other urban areas in the nation, they involved only enough sophistication to meet the federal-aid requirement.* The study of the Philadelphia region, of course, has been a very definite exception to these remarks.

The point of some interest here, however, is that the Department of Highways is currently investigating the merits of conducting similar studies for local areas with population between 25,000 and 50,000. It is interesting to note that this proposal is in no way prompted by federal pressures. The import of this investigation to the PennDOT methodological design is not highly significant, except that such additional studies would yield more data on interurban trip generation rates, just as the studies of the larger urban areas have. Furthermore, this proposal indicates initiative in the Department, which again testifies to its admirable record compared to most other states.

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* This observation reflects the 1962 Act's stipulation that such studies had to be initiated by July 1, 1965, which allowed very little time to ponder anything other than a minimum methodology.

## 2. The Villanova Effort

Several elements of the Edwards and Kelcey study suggested the need for some supplementary research into the travel patterns of rural areas. As discussed in section A above, the trip generation model in the statewide study was developed on the assumption that the data available from urban area studies were also representative of the rural areas in the State. Furthermore, the Department felt that the Edwards and Kelcey results as expressed in terms of interzonal movements did not provide enough detail for transportation planning; there was a strong desire for volume forecasts for specific highways. For these motives, the Department contracted with the Institute for Transportation Studies at Villanova to pursue two matters: (a) the conversion of the Edwards and Kelcey data from a zone-to-zone basis to the highway grid units, and (b) the development of techniques for forecasting reliably the travel patterns of rural areas (on the grid basis).

The desire for more detailed patterns of future travel demands than that prepared by Edwards and Kelcey for their "spider corridor network" touches directly upon a very sensitive issue in transportation planning. As explained quite deliberately in chapter II, transportation studies have stated their function as one of preparing skeleton networks which leave questions of specific facility design and location to the highway (and/or transportation) engineer. Highway engineers, meanwhile, have interpreted the role of

transportation planning studies as one of providing design volumes for specific roadway sections. Planners argue that their volume estimates are too uncertain for design purposes but are sufficiently accurate to evaluate skeleton network configurations or "sketch plans." Highway engineers argue that they have nothing better to refer to for design purposes. Thus, urban studies continue to provide estimates of turning movements at intersections and ramp volumes to highway engineers.

This question is just as debatable at the state level. The Edwards and Kelcey study developed a methodology to be used for planning purposes, so that a detailed network characterization was not relevant. The Department of Highways wants that study's estimated travel patterns broken down from a system of 149 zones to a system of some 1750 grid units. Without a much larger O-D survey (coded to the grid unit system), forecasts of inter-grid-unit volumes must wreak with error. Moreover, to operate a series of traffic models for such a detailed network would involve a very substantial expense. What is really needed is a methodological framework by which an entire study area (e.g., a state) first is analyzed by a series of models in terms of the skeleton network concept, and then is decomposed into individual regions which may be "blown up" and analyzed with the same series of models or parts thereof.

The second pursuit of the Villanova group involves the development of traffic prediction techniques for

nonmetropolitan areas of the Commonwealth.* Before elaborating any further, it must be emphasized that this effort was conducted entirely on the grid unit basis, and for this reason alone its results are awfully weak statistically, and even conceptually. As further testimony to support this point, note that the Villanova study of rural travel patterns analyzed the O-D data in terms of individual trip purposes, a strategy which Edwards and Kelcey considered statistically unjustifiable even at the zone level. The sample sizes reported in the Villanova memorandum confirm this suspicion.

Finally, there is a conceptual difficulty involved in the Villanova work. Years ago, it was not uncommon for planning agencies to estimate the traffic flow for an isolated O-D pair with a gravity formula which used the two nodes' populations as indicators of "magnetism." In other words, an O-D flow was estimated directly from demographic characteristics rather than interjecting an intermediate step to determine each node's individual travel propensities. As soon as entire networks began to be analyzed, however, the problem of accounting for the spatial competition between all nodes for each other's traffic led to the sequential generation-distribution approach which is so popular today and which Edwards and Kelcey used. Yet the Villanova

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* Villanova University, Institute for Transportation Studies, "Development of Traffic Prediction Techniques in Non-Metropolitan Areas of Pennsylvania," Interim Planning Memorandum II, September 1967.

analysis of rural travel patterns took the former approach. For all of the reasons stated herein, the Villanova work was not considered seriously in the methodological design for PennDOT.

### 3. Regional Analysis Approach

The Bureau of Advance Planning in the Department of Highways has recently initiated first steps toward a totally unprecedented regional approach to state highway planning. The Bureau has defined eight homogeneous regions which exhaust the entire State's area.* It intends to analyze the highway needs of each region with a planning methodology patterned very much after the urban studies that are now tapering off into a continuing phase. In effect, they will be expanding the analyses undertaken in these urban areas to encompass an entire region's highway network. Once such efforts are completed for all eight regions, the final step in this entire process will be to tie together the regional analyses to derive a statewide plan. Until now, the Bureau's activities have been based on a tentative, very subjectively derived statewide plan (see below).

The eight regions established for this novel planning effort were defined by a subjective appraisal of various county data, including: (a) agricultural land use, (b) population density, (c) physiographic features,

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* "Regional Analysis Approach to Statewide Highway Planning," Volume I, Bureau of Advance Planning, Pennsylvania Department of Highways, Harrisburg, January 1968.

(d) recreational land use, and (3) the existing highway network. Maps portraying these data were examined and counties were grouped together according to intuitive notions of homogeneity (as opposed, for example, to applying standardized regionalization computer programs which are widely used by quantitative geographers). This regionalization represents the first of three phases in the overall strategy.

The second phase will involve the development of a well-defined methodology for a transportation planning analysis of each region. This methodological design is not yet established, but "the procedure for accomplishing this objective is generally the planning process which is utilized in urban area transportation study analysis.... the technique will not be as sophisticated as that developed by urban area transportation studies...."* The following steps have been hypothesized, though they reveal very little: (a) inventories, to collect all relevant data; (b) analysis of existing conditions, or calibration of forecasting models; (c) forecasts, of future socioeconomic activity and travel patterns; and (d) systems analysis and plan development, based on a "functional classification" of highway facilities. The Bureau is currently exploring this methodological design in further detail, with the intention of conducting a pilot study in the northeast region (Region 4) which encompasses the Scranton -- Wilkes-Barre

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* "Regional Analysis Approach...," op.cit., p. 28.

area and continues up to the New York State border.* This methodology, when evolved and tested, will then be applied to the remaining seven regions.

Some preliminary thoughts on the regional forecasting model system are worth noting here in order to establish a general idea of the anticipated level of sophistication.** The analysis of any given region will have some rural emphasis and will likely be waged in terms of the grid coordinate system to permit a "blow-up" of each region beyond the zones used in the Edwards and Kelcey statewide study. The role of the Villanova study in this regional analysis will be established after that research is completed and evaluated. The forecasting system itself will probably involve a sequence of five models. The first would project socioeconomic activity and land use based on refinements of the Temple work and on very aggregately categorized land use data being collected from local sources in cooperation with the State Planning Board. Given these projections for all grid units in a region, a conventional trip generation model would next follow, perhaps with a three-purpose

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* For this northeast region they have drawn up general land use maps and are showing wooded area, state forest land, populated area, water, strip mining, open space, and farm land, and they propose to develop a slope classification so that available land will be identified. The northeast region was chosen because of a Tocks Island Report that is available for this area.

**These remarks were received from Mssrs. McMurtry, Jaroska and Shaw of the Bureau of Advance Planning in personal conversation.

break-out. Data would be collected on usage of modes other than highway, and a very simple modal split model would be applied (essentially, it would merely project existing shares). For highway trip distribution, a very simple procedure known as the Fratar model (which involves little more than prorating without any sensitivity to transportation policy) is presently being considered; no breakdown by trip purpose would be included. The Bureau of Public Roads' computer package would be used for the traffic assignment model. Thus, the anticipated order of sophistication is quite mundane.

The third phase of the regional analysis approach will be directed toward fashioning a statewide highway plan which synthesizes the results of the individual regional needs assessments. As mentioned earlier, as a basis for project planning and programming, the Bureau is currently referring to a subjectively devised ultimate composite highway network, developed "...from the best information available to date. This data was developed from meetings with Highway District personnel, urban area transportation material and plans developed by local planning commissions."* This plan was synthesized, of course, without any analysis of interactions between the component links of the future network. The third phase of the regional analysis approach, from what scant evidence is available, will likely consider such interactions between network components by the use of a

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* "Regional Analysis Approach...," op.cit., p. 30.

statewide forecasting model system. The current statewide plan will be used as an initial "test" network, suggesting that this forecasting model system may be used as an instrument for fashioning alternative statewide plans. This plan design strategy apparently will be waged in the context of a classification analysis including three functional groups of facilities: principal highways, distributor highways and connector highways.

While the concept of a regional analysis approach is quite pleasing in that it indicates initiative for developing a better planning strategy, because its methodology is not yet defined its import upon a design for PennDOT is hardly a constraining one. There is some question about the idea that planning should be done for regions first and then for the State. In particular, documentation of the ultimate statewide synthesis strategy remains too weak to see the precise reasoning behind this approach. More specifically, it is not at all clear how the recommendations for each region will reflect their impacts upon other regions. There is good reason to believe that planning at the statewide level, in terms of skeleton corridor networks, must precede the detailed analyses of individual regions if an efficient characterization of interregional interdependencies is to be achieved.

## C. Relevant Activities of the State Planning Board

In contemplating a comprehensive planning methodology for PennDOT, it is necessary to consider some aspects of

potential interface between transportation planning and other planning activities in the Commonwealth government. Specifically, a transportation planning effort requires knowledge of the spatial distribution of socioeconomic activity and patterns of land use, since these variables are typically used to forecast future travel patterns. Three aspects of these variables are relevant here: existing data, projections into the future, and development plans. The existing data question has been covered well in previous sections of this chapter, and will be summarized in chapter VI (Part Two). Regarding the latter two matters, two points deserve notice here.

First, the State Planning Board is refining the Temple University county projections of population and employment in two respects. Greater use of state population projections made by the Bureau of the Census is being made. Furthermore, the migration component of county population change is being related to employment opportunities, based upon Department of Labor data for "labor market areas" (which reduce the influence of commuting).*

Second, while no Statewide plans currently exist for any avenue of public policy (except transportation), the Board is initiating effort toward such a plan. This effort will involve two types of considerations: function-specific public investments and inducements to private development

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* Recall that the Edwards and Kelcey work did not characterize population as depending on employment, but rather formulated the opposite dependence alone.

(e.g., by reduced taxes or special services). Two functions have been given some attention already. An interim plan for outdoor recreation open space has been completed and is now being refined, and a water resources plan is also under preparation. The effort will broaden to other functions over the next three years. The PennDOT planning methodology must of course remain aware of these plans as they evolve.

A final point to be emphasized is that a meaningful interface between the State's transportation planning activities and the efforts of the State Planning Board cannot proceed under the current conflicts in areal unit systems. The Department of Highways, for various purposes, refers to a system of eleven Engineering Districts, twelve survey districts in its Statewide origin-destination survey, and eight regions as proposed for its regional analysis approach to transportation planning. The State Planning Board conducts all of its analyses in reference to a system of thirteen State Planning Regions, save for the set of seven local development districts used in connection with the Appalachian program. We recommend that PennDOT reconcile these various areal unit systems to some common denominator as a first step toward integrating the planning of transportation and land development.

# V
# GUIDELINES FOR DESIGNING THE PENNDOT PLANNING METHODOLOGY

The purpose of the research documented in this report was to design a comprehensive transportation planning methodology for the proposed Department of Transportation. The previous three chapters have reviewed the manner in which transportation planning has been practiced both in metropolitan area and state contexts, with particular emphasis given to Pennsylvania's current planning activities. Based upon this review (which was much more thorough than could possibly be documented here), the methodological design for PennDOT has taken full advantage of that experience. By characterizing the general state-of-the-art in transportation planning, a variety of key issues were highlighted, suggesting problems as often as indicating answers. The survey of current planning activities in the Commonwealth is relevant insofar as some of those activities could be incorporated directly into our design. This chapter, perhaps the most important of the entire report, reviews the major methodological issues which evolved from this review and, by explaining our positions on these issues, advances a set of criteria for our design.

Before delving into these questions, it is appropriate to emphasize a fundamental theme of the research: the role of information in planning. The discussions of the previous chapters have indicated clearly that transportation

planners have taken a giant stride in the last twenty years, a step away from piecemeal year-by-year needs assessments and toward developing truly comprehensive solutions. To a very significant extent, however, the evolution and implementation of analytical techniques associated with that stride have told us what we do not yet know. A methodology which years ago was called "comprehensive" is not yielding solutions which are comprehensive by today's standards. The need for more information is clear in all contexts, and certainly prevails in the Commonwealth. Accordingly, the methodological design for PennDOT has considered information development and technique development integrally, with the purpose of being "comprehensive" by today's and, indeed, by tomorrow's standards.

Of course, the implementation of such a truly comprehensive planning process cannot be accomplished overnight. In a very profound sense, planning really is little more than an investment in information procurement and analysis designed to yield better decisions as its return. A truly comprehensive planning methodology will yield high-quality decisions, implying lower social costs associated with misjudgment.* A partially comprehensive approach will lead

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* The concept of "social costs" as used in this and following chapters refers to all investment of both physical and human capital required of a society to maintain a given standard of living. This notion of costs is most broad, including everything of value that is foregone to attain a given end. Obviously, "value" may be expressed in dollar terms only for certain dimensions of social cost. In using the term here, we do not intend to endorse the arbitrary assignment of prices to intangibles. By the same token, we cannot agree with those who take the lack of a price as an indication that a particular cost should be excluded from relevance.

to mediocre-quality decisions, but this return is more immediate. In the face of these opposing forces of quality and urgency, the methodological design for PennDOT is fashioned in terms of an implementation program over time (see chapter XI) which maintains maximum use of information available at any given time.

This chapter elaborates upon the three major points outlined above. The following section discusses salient methodological issues, our positions on these issues, and the resulting criteria for the PennDOT design. Section B elaborates upon the information theme, placing emphasis upon the tradeoff between investment in planning for system change and actual investment in system modification itself. The final section indicates the inadequacies in data which face the Commonwealth today.

## A. Salient Methodological Issues

The design of a planning methodology for PennDOT might have taken any of a wide variety of forms, depending upon a host of fundamental issues. The previous chapters have indicated the many limitations of popular transportation planning methodology and the types of questions which have prompted spirited debate in the field. Few of these issues can be given generalized answers; the particular circumstances of any specific planning situation must be taken into consideration. The purpose of this section is to address such issues and set forth our calculated positions on each, thereby establishing a set of criteria for the methodological design.

## 1. Prespecified Guidelines

This research effort was deliberately given considerable freedom to evolve its own design criteria. However, the Governor's Committee provided some overall guidelines which served to define overall scope. In particular, the organizational design for PennDOT offered several such guidelines regarding the proposed Department's planning functions.* That document repeatedly emphasized the need to consider all modes of transport integrally and to maintain flexibility to anticipate new transport technologies. It also stressed that the Department's efforts must be closely related to other aspects of State development and associated planning efforts. A third dominant theme encouraged greater involvement by local agencies in transportation planning and decision-making activities. These and other recommendations of the organizational design are referred to liberally in the following discussion.

## 2. The Optimization Question

The most fundamental issue of overall transportation planning strategy is the question of how relevant the optimization concept is to the planning process. The PennDOT organizational design gave strong endorsement to the application of the program planning and budgeting systems (PPBS) approach, which "leans heavily on quantitative

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* "Design for a Pennsylvania Department of Transportation," Commonwealth of Pennsylvania, Governor's Committee for Transportation, February 1968.

analysis, including 'systems,' cost-effectiveness, and related types of analysis."

As discussed in the beginning of chapter II, it would be very convenient if we could establish a set of objectives for a transportation planning effort and then deduce the uniquely optimal transportation system for the Commonwealth from those objectives. No matter how the "solution" to the transportation problem is defined, however, the application of formal mathematical programming techniques is precluded by the sheer complexity of the problem. The state-of-the-art of transportation planning has only reached the point where we can predict the consequences of any hypothesized plan by means of a system of forecasting models.

Our current capabilities therefore dictate a heuristic approach to planning, whereby alternative solutions are posed, evaluated and refined through the iterative application of the forecasting model system, per the seven-task framework of chapter II. It is a sufficiently difficult challenge to couch this heuristic process into an objective framework. The methodological design for PennDOT can go no further than to face this challenge, whereby a "good" plan can be produced, but with no guarantee that it offers the "best" of all possible solutions. A strong emphasis of the design, accordingly, is directed to the problem of fashioning candidate solutions with considerably more objectivity than is inherent to the "grease pencil" approach in common use today.

## 3. The Question of Planning Goals

The point of the previous subsection is that we can indeed derive a great deal from quantitative technique and computer models, but only in a man-machine operation. The reasoning advanced was based solely upon the impossibility of phrasing the entire transportation planning problem and incorporating it into a computer which could solve that problem. We lack the hardware to do so.

Even if such technology were available, one other inhibiting force would be encountered, namely, the definition of goals. Again, the PennDOT organizational design stated that "the...PPBS...approach emphasizes careful formulation of departmental objectives and analysis of alternative means for meeting objectives." The weakest link, however, in all public (and even industrial) planning efforts is what should be the very first one: defining objectives. In all transportation planning efforts to date, regional goals either have not been defined at all or have been defined very nebulously. Granted, many studies have adopted an objective of minimizing total transportation costs, but their recommendations typically are revised quite substantially upon being subjected to the political process which reflects broader community concerns.

Before taking a position on this issue, the concept of planning objectives requires clear interpretation. In order to have a solid idea of how to generate "alternative means for meeting objectives," we must not only know the specific dimensions of those objectives but we must also

know the relative importance of each. The difficulty with multidimensional goal structures is that pursuing one objective typically denies another. Only by knowing the relative importances of each might we properly and succinctly deal with goal-goal tradeoffs and "optimize" in any sense.

The problem is a strong focus of current research. Several studies have already concluded that goals definition is a fruitless task for long-range planning, since relative weightings of competing criteria are too subjective to succumb to measurement. Rather than asking "what objectives do we want a region's transportation system to meet and how important is each?," these studies recommend that planners merely ask "what objectives are substantially relevant?" and then provide the decision-making structure with adequate information on those objectives. The weighting of competing objectives can then be manifested through the operation of the political mechanism. Considering the absence of a counterpoint, the PennDOT methodological design must accept this point of view until further research demonstrates otherwise. Nevertheless, we do point out the directions along which outstanding research is proceeding.

## 4. The Limits of Objectivity

The emphasis of this report is on the development of objective analytical technique which will promote well-informed and well-structured transportation decisions in the Commonwealth. We believe strongly in the capability of

computer models to promote consistent decisions which rest on solid rationale. In particular, we maintain that the area of planning which most lacks such objectivity and decidedly needs a more liberal dose of it is the problem of fashioning alternative transportation plans. This point was emphasized in the above-cited excerpt from the organizational design, and must be underscored in view of our attitude toward defining objectives.

Equally important, we hardly believe that objectivity conquers all. Indeed, as indicated above, calculated doses of subjectivity are necessary adjuncts to the planning process in two specific respects. First, the problem of fashioning alternatives can benefit substantially from the intuitive notions of experienced transportation planners: numbers simply will not substitute for creative imagination. Second, the final evaluation of alternative plans ultimately must rest with policy-makers rather than depend upon a mere benefit-cost calculus. This point is particularly crucial if indirect effects are deemed to be relevant criteria (see below). The methodological design for PennDOT stresses objectivity, but in so doing places necessarily subjective elements in their proper context.

## 5. Interactions With Other Statewide Planning

The organizational design for PennDOT places emphasis upon interaction with other planning activities in the Commonwealth. Let us distinguish between two types of such companion activities: those (non-transportation)

efforts at the Statewide level, and those (transportation and other) efforts at local and regional levels. The latter type of relationship is discussed under point 7 below; the concern here is with liaison between PennDOT and other Statewide planning efforts.

The basic purpose of such liaison is to ensure that the Commonwealth's transportation plan is compatible with its broader development plans. This liaison has two conceivable aspects. As a minimum, the transportation planning methodology should take other plans as given inputs to the extent that such broader development policies will affect the pattern of future travel demand. On the other hand, the transportation planning effort ideally would be more normatively oriented, whereby transportation is viewed as an instrument for achieving Statewide development objectives. As discussed above, the problem of defining goals is at least as difficult for broader developmental planning as it is for transportation planning. Pending further research, the most we can do is to encourage an awareness of what transportation might do for State development, to provide for the quotation of information on same, and to consider developmental criteria in fashioning alternative plans.

Regarding the minimum type of liaison, the PennDOT planning effort should be aware of the State Planning Board's Statewide "functional plans" (see chapter IV) as they evolve over the next three years. Such plans should be translated into their expected effects upon the future pattern of traffic generation. In order to do so, either

PennDOT or the Planning Board must analyze the impact of specific development projects upon the spatial distribution of socioeconomic activity and land use within the Commonwealth. While this task would appear to be the Board's responsibility, their current methodology merely projects socioeconomic activity measures upon which indices of development potential are based, and investments are then channeled into areas with the highest potentials. Their strategy does not consider the feedback aspect, i.e., the impacts such investments might have upon future socioeconomic activity.

The attitude taken in the PennDOT methodological design is that the character of socioeconomic forecasting models appropriate to comprehensive transportation planning must be sensitive to both transportation and other public policy (see below). Therefore, while avoiding undue sophistication, the socioeconomic activity model in the PennDOT methodology shall be sufficiently broad to offer a multipurpose function in the sense that the Planning Board might use it for its own planning analyses.

Before closing this discussion on inter-agency planning liaison, some mention should be given to extra-Pennsylvania transportation planning efforts and our attitude toward them. Chapter III discussed the Mississippi Valley Screenline Study, a joint data collection effort among at least eight Midwestern states. There are distinct advantages and also some drawbacks inherent to the concept of cooperative interstate planning. A particular advantage is that

economies of scale in data procurement can be realized.* Whether PennDOT should pursue such a venture with adjacent states is a policy question beyond the scope of this study. We have designed a methodology for planning the Commonwealth's future transportation system, and that alone. However, we strongly endorse an active involvement with the Northeast Corridor Transportation Project, the study of which includes fifteen counties in the southeastern part of the State. It should also be noted that the idea of data sharing should be pursued with the State Planning Board as well as with the NECTP.

## 6. Long Range vs. Incremental Planning

Chapter II highlighted the frequently debated issue of what a transportation plan should be and its implications to planning strategy. It is widely accepted that a meaningful characterization of a region's transportation system can be achieved only in reference to the network (i.e., spatial configuration) of transportation facilities, for any given point in time. The focus of debate regards the most appropriate temporal disposition of this characterization: should we be producing a transportation plan for a horizon twenty or more years hence, or should we be taking smaller steps and smaller steps only?

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* Also, origin-destination studies conducted for just one state independently of surrounding states permit only a very rough measurement of "bridge" or through traffic, i.e., traffic with origin and destination outside that state. Interchange of such data between adjacent states can be quite useful in this respect.

Proponents of an incremental planning approach argue that long-range plans tend to be revised so frequently that they lose their meaning. Certainly any horizon plan may require revision to reflect (a) unforeseen technological developments, (b) major contingencies such as war, depression and other catastrophic circumstances, and (c) major changes in objectives (to the extent they can be defined). Those proponents maintain that we are so incapable of articulating goals that any particular formulation is not likely to be stable.

To a large extent, this point makes reference to the turnover in political representation characteristic of most jurisdictional levels in the United States (or the turnover in attitudes of incumbents). The argument ignores the fact that almost all horizon-year transportation plans prepared for metropolitan areas (where revisions are typical) failed to consider criteria other than the traditional cost measures of engineering economics. A broader perspective during original planning efforts quite likely would have reduced the need to revise such horizon-year plans. Whether it be the Commonwealth or any other jurisdiction, the planning effort must cooperate with the political framework and become familiar with the broader criteria inherent to that framework. Otherwise, the planning effort cannot be very informative, and its conclusions will be foregone ones.

By the same token, the political framework must take the transportation planner seriously by helping to articulate relevant criteria. Pennsylvania as a whole is suffering from

outmigration and a decline in certain important components of its economic base. The political structure must appreciate the fact that a competent planning effort can evolve effective strategies for curbing such trends. A perspective which is concerned exclusively with the allocation of highway mileage to local areas is a very narrow one. The proposed Department of Transportation would be planning transportation on a Statewide basis (see the following subsection) and would be concerned with State development issues such as attracting people and firms. These are not issues which are solved by hesitant incrementalism. A long-range planning approach is more appropriate, and must be taken seriously.

Of course, in advancing these arguments for a horizon-year planning strategy, we do not deny the vital role which incremental planning can play. The next subsection discusses the horizon plan as a "master" concept which shall guide all transportation decisions at Statewide and at regional and local levels. These decisions are necessarily spread through time. Indeed, we should also point out that the notion of a horizon-year plan is not a rigid and static one. Admittedly, unforeseen changes in technology, environment and socially relevant criteria will occur. Such "shocks" will call for revisions of long-range plans; our point is that only these sorts of major contingencies should prompt such revisions. Moreover, the mere fact that time does not stand still requires that the long-range planning process extend its telescope further into the future on a

relatively continuous basis. For example, if the horizon year for today's planning efforts is taken as 1990, by 1975 a long-range plan should be fashioned for 1995, and so forth. In these respects, the concept of a horizon year is a dynamic one.

## 7. The "Master Plan" Concept

The Commonwealth's transportation system is a very complex superposition of fixed plant facilities, vehicles and operating rules which together represent a countless number of decisions of widely varying scope. Decisions about investment, regulation, design, operations, and promotion by both the public and private sectors are continually changing that transportation system. Commitments to that system vary widely in terms of the time and space dimensions. For example, decisions about the general character and location of major highway facilities are roughed out up to six years in advance of construction; yet final designs and route locations are worked out one to two years prior to construction, and decisions about bus scheduling or intersection signalization on those highways may involve quite short-run responses to special circumstances such as parades or athletic events. Some decisions are of Statewide scope, others of regional scope, and still others are concerned only with individual road sections or intersections. Similarly, some decisions are of a long-run programming character, while others are more short-run, perhaps even spontaneous ones. Obviously, it is neither

possible not desirable to concentrate all of these decisions into one central planning effort.

The Commonwealth's transportation problems are felt at all levels of geographic space and by all perspectives of future time. A fundamental issue in designing a planning methodology for PennDOT involves just how to carve into this problem in terms of its space and time perspectives. To an appreciable extent, transportation policy toward one part of the State can have impact upon transportation problems and policies in all other parts of the State. Similarly, there are interactions between transportation problems and solutions in terms of when they are staged through time. What we are after is a planning methodology which will cope with the transportation problem to the extent that such interactions over space and through time are significant at the State level. In other words, the methodology shall be designed to evolve a "master plan" which not only will guide long-run decisions at the State level but will furthermore serve as a template to guide more short-run decisions at more local levels.

Such an approach is quite consistent with the recommendation of PennDOT's organizational design to "...increase local government capacity for effective transportation planning and improvement, on the grounds that decisions vitally affecting local and regional development should be made, insofar as possible, by the governments concerned..." We're after a broadly defined, long-run sketch solution to the Statewide problem upon which lower echelons of decision-

making can amplify both in terms of detailed locations and temporal staging of transportation improvements.

In the previous subsection it was argued that a long-run "horizon-year" approach is required in order to handle adequately the Commonwealth's major transportation and development problems. This approach amounts to characterizing the time stream of future transportation problems at one representative point in time, roughly a generation away (the acceptable limits of forecasting prowess). Inherent to the horizon-year concept is the assumption that inter-spatial interactions are much more important at the Statewide level than intertemporal interactions between components of the transportation system. Practically all urban, regional and state transportation planning efforts have been predicated upon precisely this assumption.* The forecasting model system for PennDOT will be designed to operate recursively, whereby the time period between the base year and the horizon year shall be divided into increments of five or so years; the model system may be applied for each of these intervals, thereby allowing for rough alterations in plan staging. Beyond this, more detailed investigation of when to initiate particular components of a horizon-year plan is left to engineers.

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* Not only have past planning efforts deemed it infeasible to consider the time dimension simultaneously with the analysis of spatial interactions, but the few attempts at developing a meaningful model of the staging problem itself have proved infeasible.

Accepting this point, the issue condenses to one of carving an appropriate perspective for analyzing spatial interactions among network components. Based largely upon intuitive notions about the relationship between transportation and land use, supplemented by approximate estimates of mean trip length of the State's transportation consumers and by considerations of feasibility in model development, we feel quite unjustified in recommending an areal granularity more detailed than the Edwards and Kelcey zone system as a basis for Statewide analysis, even if travel data at the Highway Department's grid unit level were available on a statistically satisfactory basis. This position decidedly infers that the Statewide methodology be limited strictly to an interurban character. More local problems such as those encountered in urban areas will be left to regional and local planning efforts, except to the extent that transportation decisions for local areas have significant impact upon a wide periphery.

This design criterion is accompanied with the attitude that the regional analysis approach currently contemplated by the Department's Bureau of Advance Planning shall be retained as a vital tool in amplifying the master plan evolved by PennDOT. Regarding the methodology which might best be employed by such regional analyses, a subset of the system of forecasting models recommended for the Statewide analysis would be easily adaptable to such regional planning, presumably to be conducted in reference to a finer areal granularity such as the Department's grid units. Of course,

this point suggests that such regional planning take advantage of the multimodal perspective so inherent to the Statewide methodology.

Note that this strategy resolves a question directed to the regional approach in the previous chapter regarding how individual regional analyses might be synthesized into a Statewide plan. While the Bureau's thoughts on this matter are in too embryonic a stage to suggest how such a synthesis might be accomplished, the attitude of this report is that Statewide analysis must precede rather than follow the individual regional analyses. Regardless of which ordering might be chosen, feedback from one to the other must obviously occur. We feel that the Statewide perspective must govern local commitments rather than be predicated upon them; otherwise the solution to the entire State's transportation problem can only involve a potpourri of subsolutions to a variety of subproblems, which does not necessarily prove to be consistent with the State's interest.

With equally strong conviction, moreover, we argue that the intensity of feedback activity will be less if the Statewide master plan governs the regional and urban analyses. It must be emphasized, however, that the PennDOT methodological design must make sufficient provision for feedback from local interests as part of the plan evaluation phase. In sum, dialogue between Statewide and local planning efforts is essential, but is accommodated most efficiently if the Statewide perspective is assigned the protagonist role through the instrument of a master plan as defined above.

## 8. The Multimodal Perspective

Perhaps the most frequently expressed attitude toward the proposed Department of Transportation is the importance of considering all modes of transport (even those in the experimental stage) in the context of one integral and "balanced" system. Certainly one of the main reasons that the current practice of transportation planning is not really "comprehensive" is that studies tend to treat individual modes as self-contained systems. Several criteria for a truly comprehensive PennDOT methodology may be cited in this regard.

To the extent that past and current transportation studies consider different modes in the context of a total network system, they do so only in the process of network analysis vis-a-vis network synthesis or design. Network synthesis, on the other hand, refers to the process of choosing suitable components for a future system. That is, network synthesis involves the generation of alternative plans, while analysis estimates the (direct) effects or performance of such plans. The problem was cited in chapter II as one of the weakest parts of the entire planning process, even if only the highway mode is considered. The introduction of other modes compounds the problem severely.

On the analysis side, there are reasonably well-developed "modal split" models which estimate the manner in which travel demand will allocate itself to competing modes. However, practically all of these operational models have two limitations which should be circumvented by the PennDOT

design. First, they fail to consider an entire trip, including access at both ends; they break up the problem so that any trip involving an intermodal transfer is redefined as two trips. This latter approximation is related to the second limitation, namely, that modal allocations frequently refer to the institutional labels of alternative modes as explanatory variables rather than referring strictly to their relative service characteristics.

Notions such as "captive transit ridership" may make some sense in urban areas where only two "modes" are available. At the State level, however, it no longer is reasonable to characterize a particular technology by what the public calls it. Rather, any given mode must be represented by a collection of characteristics which the consumer purchases (e.g., speed, capacity, comfort).* Only by such an approach can novel technologies be handled adequately, including service coordination between existing modes.

On the synthesis side, the first point to be realized is that the transportation planning and engineering professions have contributed nothing of an analytical nature. Many references are made in transportation literature to the concept of balance among modes, but few realize how distant

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* This line of thought is supported by recent advances in the economist's theory of consumer demand. See Lancaster, K.J., "A New Approach to Consumer Theory," Journal of Political Economy, Volume LXXIV (April 1966), pp. 132-157.

we are from knowing how to determine "economical and efficient combinations of modes."

In plain terms, the transportation field is embarrassingly ignorant of how to go about determining which kinds of technology to be provided in what locations. The typical metropolitan area study dedicates itself to the foregone conclusion that rail transit shall be developed radially around the central business district while highways are to follow existing corridors of high demand. A network is fashioned with a grease pencil for each of the two modes independently of each other. To the meager extent that objectivity exists, it exists only in the design of a highway network.

The implication of all this to our methodological design is that we are without significant precedent. In six months' time, the most that could be accomplished was to structure the problem and the directions of current and future research. As discussed in subsection 2 above, a heuristic approach to fashioning plans is our only recourse whether we deal with one mode or many technologies. Thus, pending contact with (and perhaps funding of) future research, the planner's intuition and his grease pencil must play a dominant role in dealing with the multimodal design issue for PennDOT. To the extent that a more objective approach has been adapted within the six-month study period, the emphasis has been on conventional highway technology, in accordance with the organizational design's recommendations.

## 9. Transport-Sensitivity and the Forecasting Model System

Chapter II identified five components of temporal adjustment in travel patterns, and argued that the "induced" and "shifted" components are almost totally ignored. The purpose of a forecasting model system is to estimate the total response of society to transportation policy, including these two components. Most transportation studies have employed demand forecasting techniques which are sensitive to hypothesized network change, but few have projected socioeconomic activity with any such sensitivity. It is our conviction that many transportation studies have consistently underestimated future travel demand largely because of this assumption that changes in transport supply will not have significant impact upon the socioeconomic factors responsible for traffic generation.

The forecasting model system for PennDOT must capture the sensitivity of socioeconomic activity to transportation. It is senseless to assume that the level of transportation service will affect firms' and households' transportation demands but that it will not affect their activity levels and locational decisions. This point is particularly salient for PennDOT, whose responsibilities will include a very large investment in transportation over a long period of time for a very large geographic area. Moreover, without capturing this sensitivity the methodology cannot conceivably cater to any notion of using transportation as an instrument to pursue broad, Statewide development

criteria.*

This sensitivity of socioeconomic activity to transportation is most conveniently captured within the conventional allocation approach common to all transportation planning methodologies. That is, a control total of such activity (e.g., total population) is first established for the entire study area without sensitivity to transportation, and this total is allocated to subareas in a manner which reflects the relative accessibility advantages of such subareas. In other words, transport-sensitivity is most easily incorporated in terms of an analysis of spatial distribution.

Ideally, we would develop such an allocation model for the entire United States so that we could represent the competition between Pennsylvania and all other states for firms and people. Only by this grand approach might we be able to trace, for example, expected migration from the Commonwealth to California. One argument against this nationwide approach (aside from its obvious infeasibility for PennDOT) is that it would require knowledge of all other states' transportation plans. Strictly speaking, the planning of transportation for Pennsylvania must limit itself to an analysis of spatial distribution within the

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* The Governor's Committee has already emphasized the need for such a comprehensive forecasting model system. In a memorandum to Governor Shafer (January 11, 1967), Chairman Hazard recommended that the computer model system "reflect existing and future technological, economic and demographic impact." See "Design for a Pennsylvania Department of Transportation," op.cit., p. 24.

State, since even the plans of adjacent states are not known precisely. Such an approach, however, would permit no objective statements whatsoever about the State's expected migration pattern and what transportation investment in the Commonwealth might do to that pattern.

We are interested in estimating the effects of transportation improvements in the Commonwealth upon both the spatial distribution of socioeconomic activity within the State and upon interstate migration. The former can be handled quite adequately; some compromise position must be taken on the latter point, in view of the previous discussion. We believe that the ultimate planning methodology for PennDOT must consider a study area which circumscribes significant portions of adjacent states, and accordingly must make tacit assumptions about those states' future transportation plans to the extent that support information can be supplied by those states. This position obviously favors some degree of interstate cooperation.

The rationale for this approach is quite straightforward. Such a modeling approach will capture the competition for firms and households among subareas within the Middle Atlantic Region. It assumes that the competition for firms and households between that Region and other regions of the nation is not significantly related to transportation. In other words, we do not believe that industries and people are moving from Pennsylvania to California primarily because the West Coast has better highways. However, we believe that future firms and households which are

committed to the Middle Atlantic Region for non-transportation reasons will tend to locate within some part of the Commonwealth if that area has a relative advantage in terms of accessibility. The socioeconomic impact model in the PennDOT forecasting model system therefore will be designed with the flexibility to extend the scope to such extra-Pennsylvania territory as its planning staff sees fit.

## 10. Data Resources

The preceding nine subsections discussed a variety of key issues in methodological design, and indicated what directions would be ideal for PennDOT. At various points in the discussion, reference was made to the practical consideration of ensuring feasible implementation. As a fitting conclusion to this section, we reemphasize the crucial role which this feasibility criterion, in terms of both computer techniques and data, must be accorded in the design. Without question, the matter of data resources overrides that of techniques. To derive totally "comprehensive" solutions to Pennsylvania's transportation problem, PennDOT would require a near-infinite reservoir of information. Obviously, the true challenge of the methodological design is to settle for something less, but something which gives adequate return for every additional dollar invested in further data procurement. The following section amplifies this theme.

## B. The Role of Information in the PennDOT Methodology

As discussed at the beginning of this chapter, the connotation of the term "comprehensive" in transportation planning has become much broader than it was years ago. What was originally conceived as a comprehensive approach has now been evaluated, its many limitations have been recognized, and the fact that even this approach is yielding only "partial" solutions is now evident. Recall chapter II's point that "urban transportation studies have an embarrassing record of accomplishing little else than involving more vehicles on more highways at preplanning congestion levels."

It is the nature of problem-solving that improvements in solution technique tend to reveal the short-sightedness of prior technique. To some, this observation may prompt the reaction that "sophistication breeds sophistication, so why bother rolling the snowball?" Others believe that sophistication, like so many commodities, has a point of diminishing returns, and the real challenge lies in striving to reach and only reach that point.

While its counterparts in other areas of public policy (save for water resources) continue to operate with a totally piecemeal approach, transportation planning has taken one giant stride by adopting selected techniques of systems analysis. This initative has led to a payoff (over and above improved solutions) which planners of recreation, health, education and so forth envy: experienced transportation planners now have a rough idea of what their ideal approach might be.

Furthermore, it is clear that current concepts of systems analysis (including those yet to be operationalized by transportation studies) are rather adequate for such an ideal approach. The real obstacles are the limitations of computational technology and information. Progress in computer technology is proceeding at a very encouraging pace, though we can always demand more of it than it is capable of providing. Information, on the other hand, is there for the asking. A critical difficulty in planning today is that a high value is placed upon answers *per se*, without much regard to their accuracy.

This report is predicated on the position that transportation planning activity in the Commonwealth is inadequate. To a commendable extent, much of this activity has kept pace with the state-of-the-art of transportation planning in all contexts. The Department of Highways, both in its recent Statewide O-D study and with regard to its contemplated regional analysis approach, has favored a methodology used at least by the less sophisticated of the metropolitan studies. Yet almost all of the urban studies have been concerned primarily with producing *a* solution rather than with producing *an accurate and comprehensive* solution. Indeed, the entire field of transportation planning has paid far too little attention to the accuracy of the solutions it has been offering, and almost no attention

to the role which additional information might play in improving those solutions.*

Past studies have ready apology for their "partial" approaches, a defense which is easy to sympathize with: insufficient funds for data collection. Resource constraints upon procuring information required for adequate planning of transportation systems have been quite stingy, particularly when compared to the consequent social costs of constructing inadequate facilities. The inevitable trend, however, is toward the position that an additional million dollars spent on data collection and processing may well lead to transportation investment decisions which realize social savings several orders of magnitude greater than that million, given sound data management. Transportation planning can be no more effective than the information upon which it is based.

The beginning paragraphs of this chapter presented the viewpoint that planning represents an investment in information designed to yield better decisions about system change -- and therefore lower social costs -- as its return. This perspective is not totally without precedent. Two recent research efforts sponsored by two very reputable organizations

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* The U.S. Bureau of Public Roads is presently sponsoring a study by CONSAD Research Corporation of the significance of errors inherent in current techniques used for urban travel forecasting. The study includes the development of a cost-effectiveness framework for improving that entire forecasting process by various means, including the procurement of additional information.

(National Cooperative Highway Research Program* and the American Society of Civil Engineers**) have pursued this line of inquiry in some detail. Thomas and Schofer molded the problem of identifying relevant evaluation criteria within this type of framework, thereby clarifying the trade-off between expenditure on information and the social costs of poorly informed decision making.

The work of Snell is particularly interesting here because it discusses the tradeoff between investment in planning for system change (which we maintain is really equivalent to investment in information) and investment in system change itself. His point is quite simple:***

> The appropriate intensiveness of planning expenditures and the duration of planning activity can be determined only by considering both planning costs and the returns of the system change it specifies in addition to viewing the planning process by itself.

Of course, this framework is not very susceptible to quantification, but it provides a convenient structure for expressing the central theme of this report.

Figure V-1 depicts two alternative strategies for allocating a given annual budget (assumed constant for

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* Thomas, E.N. and Schofer, J.L., "Strategies for the Evaluation of Alternative Transportation Plans," Part I, Final Report, National Cooperative Highway Research Project 8-4, The Transportation Center at Northwestern University, Evanston, July 1967.

** Snell, J.E., "A Framework for the Analysis of Urban Transportation Research," Ph.D. Dissertation, Department of Civil Engineering, Northwestern University, Evanston, June 1966.

***Snell, J.E., ibid., pp. 27-28.

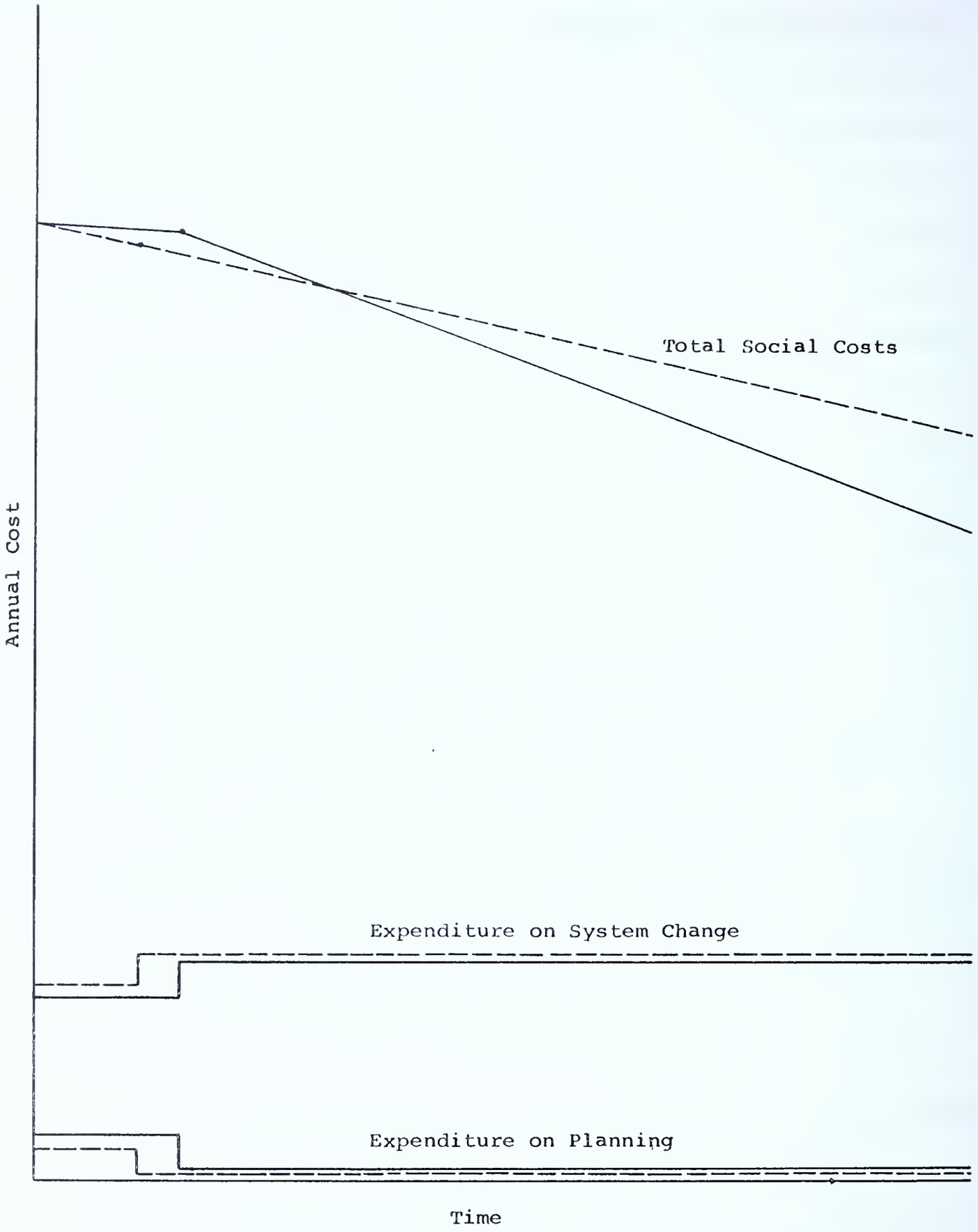


Figure V-1. Two Alternative Strategies for Allocating a Total Transportation Budget to Planning Activity and to Actual System Change

simplicity) to the two activities of planning and system change, and their relationships to total social costs. The strategy indicated by the dashed lines allocates less to planning (and information procurement) than does the solid-line strategy. Both strategies involve a relatively intense threshold planning effort during which a modeling system and peripheral methodology is implemented; both also involve a continuous activity at a much lower annual cost. The dashed-line strategy involves less expenditure in both of these stages, and its threshold effort is briefer, i.e., its methodology is implemented sooner than that of the solid-line strategy.

The key point regards each's effect upon total social costs. In either case, total social costs are lowered by system change. Because of its briefer implementation period, the dashed-line approach effectuates a greater reduction in total costs immediately. However, the solid-line strategy, which involves more expenditure of monetary and time resources on planning activity, is portrayed to effectuate substantially lower total costs, beginning only a short while after its methodology is implemented. Thus, even though it diverts some additional resources away from the system change activity itself, the additional investment in planning results in a much more cogently calculated plan for system change.

Of course, immediate reductions in total cost must be weighted more highly than savings in the long-run, in accordance with classical principles of engineering economics.

However, the intention of this example is to demonstrate that a well-informed planning strategy may lead to long-run savings which, even when discounted, very much outweigh the benefits of a poorly-informed planning effort.* Naturally, there are limitations to this argument, as Snell states well:**

> ...one would expect a threshold duration for planning below which little of value is accomplished...Similarly, at the other end of the scale, one would expect rather rapidly diminishing returns from extended planning activity -- due in the extreme to nothing else but the stubborn refusal of the future to be bribed into full view at any price.

The objective of the PennDOT methodological design is to fashion a comprehensive planning strategy, including additional information procurement, which intuitively appears to give the greatest savings in social costs per unit of resources invested in both the planning and system change activities.

## C. The Current Data Situation

Considering the very important role we have assigned to information, it behooves us to comment on current data inadequacies as a last preliminary to presenting the actual

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* In allowing for the greater importance to be attached to more immediate benefits, we acknowledge the argument that construction costs increase with time. Too frequently, however, proponents of this argument fail to admit that all prices in the economy increase as do prices for construction services. There is absolutely no reason to suspect, then, that the social costs of inadequate planning stay constant while construction costs increase.

**Snell, J.E., op.cit., p. 28.

methodological design. Data relevant to transportation planning fall into three categories: (a) socioeconomic activity, (b) transportation network characteristics, and (c) network travel patterns. Models which estimate direct effects portray network travel patterns as a function of socioeconomic activity and network characteristics. Models which estimate indirect effects portray socioeconomic characteristics as a function of network characteristics, in terms of economic and demographic activity interdependencies. Each of the three categories is discussed in turn below.

## 1. Socioeconomic Activity

Socioeconomic data relevant to transportation planning include all measures of economic and demographic activity to which the character of observed travel patterns might be attributed. Examples of measures frequently used include employment and dollar output for industrial sectors, and population, income and auto ownership for household classes. As a minimum, such information must be available for each traffic analysis zone for one "base year." Time-series information merely for the total study area is adequate for the "control-total allocation" approach common to practically all studies' forecasting model systems. Any available projections for the entire study area in the future, of course, are quite welcome.

A wealth of economic and demographic data is reported by many sources, the most comprehensive and uniform of which is the U.S. Bureau of the Census. The Bureau's

decennial Census of Population documents report extensive demographic data at the "minor civil division" level.* Economic data are also reported by a wide variety of sources; again, the Bureau of the Census predominates with its nearly-annual County Business Patterns series (employment by county, by at least nine industrial categories, by place-of-work) and its Censuses of Business, Manufactures, Mineral Industries, and Transportation (all taken at least for 1963 with another battery intended for 1968). Except for the Census of Transportation, these documents report economic data at the county level. Documents are published by the Commonwealth which are derived directly from the aforementioned sources.

In contrast to the other categories of required data, then, quite a bit of information is available on socioeconomic activity. All of this data, however, is reported for individual industrial sectors and household classes for individual areal units. Characteristics of interindustrial interactions, on the other hand, are surveyed and reported only for the nation as a whole.** Except for the recent input-output study of the Philadelphia area,*** then, we

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* The 1960 Census, for example, includes such characteristics as: population (classified as urban, rural farm, or rural non-farm); migration statistics; age distribution; sex and race characteristics; rather aggregate statistics on journey-to-work; income and income distribution; education; and employment (by place-of-residence) by occupation and industry.

**"Survey of Current Business," Office of Business Economics, U.S. Department of Commerce, 1958.

***Isard, W., Langford, T.W., Jr. and Romanoff, E., "Philadelphia Region Input-Output Study," Regional Science Research Institute, Philadelphia, undated.

know nothing about interindustrial structure within the Commonwealth beyond what we might care to infer rather loosely from national data. In our opinion, information of this sort for various areas within the Commonwealth would be of tremendous value not only for transportation planning but for all other State planning activities.

Projections of economic and demographic activity are available, at the state level, from three Federal agencies. Estimates of employment, output and related industrial measures have been prepared at least through 1975 by the National Planning Association. Projections of demographic activity have been issued by the Outdoor Recreation Resources Review Commission (through 2000) and the Bureau of the Census.

## 2. Network Characteristics

This category of data includes all relevant performance parameters for each link and node in the network to be analyzed.* These parameters include measures of capacity and any of a variety of service attributes such as speed (or average travel time), cost to the user, and scheduled frequencies. The service attributes are particularly crucial to transportation planning, since it is through these variables that a forecasting model system is rendered sensitive to system modification. These measures are the fundamental independent variables used to explain patterns of route, mode and destination choice, and locational

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* Chapter II called this set of parameters the "abstract network description."

patterns of socioeconomic activity. In stating that such variables are desired for each link and node, detail by mode and for freight and passenger service is inferred.

Existing data on the Commonwealth's network characteristics are quite weak, except for automobile transportation. For Statewide inventories conducted by the Department of Highways, link capacities and average auto travel times are readily abstracted. The Infrastructure Survey compiled by Wilbur Smith and Associates for the Governor's Committee depicts the spatial configuration of each mode's subnetwork and capacities of their individual components. Some data are reported on service attributes for passenger transportation, but very little information is available on measures of freight service. Generally speaking, average travel times, frequencies and fares would be quite useful for passenger analysis, and average costs to the shipper (or consignee) are required for meaningful freight analysis. Passenger travel times could be roughed out by assuming average speeds for each mode. Shipping costs of freight, however, cannot be determined without survey work. Given available data, then, the total absence of freight cost information precludes any transport-sensitive treatment of commodity flows.

### 3. Network Travel Patterns

Existing inadequacies in data on network travel patterns also reflect the fact that highways have dominated all planning efforts. For any meaningful analysis of a multimodal

nature, origin-destination flows (between all pairs of traffic analysis zones) for all modes combined and for each mode individually are required, for passenger and freight, for some base year.

All that is currently available are vehicle (and therefore passenger) flows for the highway mode and passenger flows for the air mode (from the Civil Aeronautics Board, as reported in the Infrastructure Survey). Freight flows are available on an origin-destination basis for the Commonwealth only for the air mode, and this information was obtained (in the Infrastructure Survey) only by surveying individual carriers. The Interstate Commerce Commission and the Bureau of the Census publish O-D freight flows between large areal units (e.g., states and SMSA's), but do not ordinarily tabulate such information for detailed areal unit systems such as counties, because of their disclosure restrictions and low sample sizes. Without question, then, the limitations of existing data preclude any comprehensive analysis of freight traffic patterns, and also preclude meaningful treatment of passenger travel for modes other than auto and air.

## 4. Summary

To summarize this subsection, available data fall far short of what a comprehensive transportation planning methodology requires. By "comprehensive", we mean only the following three points: (a) it must include all modes; (b) it must consider both passenger and freight

traffic; and (c) it must consider the impact of transportation service improvements upon the spatial distribution of socioeconomic activity.

As far as the multimodal issue is concerned, we do not even know the total flows over all modes combined between exhaustive subareas of the State. This point holds for both passenger and freight transportation, but is much more so for freight.

A bimodal analysis of passenger traffic could be waged in a network context, but would dictate the assumption that rail passenger flows between traffic analysis zones (say counties) are negligible compared to utilizations of the air and auto mode. Existing data inadequacies for freight network characteristics and flow patterns are so severe that freight transportation unequivocably cannot be considered in a network context without a quite substantial survey effort.

The impact of highway and air transportation improvements upon the spatial distribution of socioeconomic activity can be gauged rather crudely, but only in a manner which must ignore interindustrial interdependencies. The impact of improvements in freight transportation upon the State's economic situation cannot be treated at all, given existing data limitations. It is the freight transportation system which constitutes the backbone of Pennsylvania's economy, so the matter of guiding State economic development cannot be pursued without substantial survey work.

In sum, only by intiating a rather thorough survey of economic activity in the State can PennDOT expect to plan

on a truly comprehensive basis. A reasonably adequate methodology can be implemented rather promptly to deal with passenger transportation at the Statewide level. The bare facts, however, make it quite clear that the Commonwealth knows almost nothing about its economic structure and the manner in which freight transportation serves or fails to serve that structure. In order to fashion effective strategies for promoting Pennsylvania's attractiveness to industry (and potential residents), be they transportation policies or other developmental strategies, PennDOT must first take major steps to understand the State's complicated economic structure. In short, the need for improved technique is not overbearing at all, compared to the need for more information. This conclusion is quite similar to the points of view underlying the Connecticut and California studies discussed in chapter III. Part Two of this report presents a comprehensive methodological design for PennDOT, in terms of analytical techniques and information require-ments.

# PART II

# VI
# OVERVIEW OF THE RECOMMENDED METHODOLOGY

Part One of this report established key points of departure for the PennDOT methodological design, including the general state-of-the-art of transportation planning in urban, regional and state contexts, and a review of methodology and data currently being used to plan transportation in the Commonwealth. The major implications of that review were captured in chapter V, which evolved a set of design criteria with particular emphasis given to the need for substantially more information. Part Two presents a detailed articulation of our methodological design. This first chapter gives an overview of that design.

The general structure of this second Part follows the seven-task characterization of the transportation planning process introduced in chapter II:

(1) identification of relevant policy variables

(2) identification of relevant consequences or effect variables

(3) collection of information required for task 4

(4) development of the "forecasting model system" (which relates effect variables to policy variables)

(5) generation of alternative transportation investment strategies

(6) application of the forecasting model system to estimate the relevant consequences of each alternative

(7) selection of a "best" alternative by a comparative evaluation of each alternative's consequences and capital costs

The first three steps listed involve defining the scope of a new planning effort and its information requirements, and will be discussed in this chapter. The remaining steps involve the design and implementation of a forecasting model system and the use of that model system to fashion alternative transportation plans. These matters are given elaboration in subsequent chapters, but receive brief overview in the latter sections of this chapter.

## A. Relevant Policy Variables

The first two steps in the aforementioned characterization of the transportation planning process are of a preliminary nature, and to a large extent are fulfilled here. In other words, we are not designing a strategy for identifying relevant policy and effect variables; we are recommending here what variables should indeed be considered. This section discusses the appropriate span of control for PennDOT's Statewide planning efforts, i.e., relevant policy variables.

### 1. The "Master Plan" Description

The ultimate purpose of the proposed PennDOT planning methodology is to produce a long-range "master plan" which will guide all major transportation decisions of a Statewide nature and the myriad of decisions of local and regional agencies. As such, this master plan shall depict a broad spatial configuration of transportation facilities of various types, accompanied by rather rough notions of when to initiate the implementation of the master plan's various components.

The phrase "spatial configuration of transportation facilities of various types" infers the definition of a traffic analysis zone system and an abstract network which depicts the geographic arrangement of transportation facilities of all modes as they connect those analysis zones to each other. More specifically, each "link" and/or "node" in the abstract network is to be characterized in terms of fundamental parameters measuring that component's capacity and its key service attributes, namely, the average cost and average travel time occasioned by users of that (and every) component.

In other words, the product of the proposed PennDOT planning methodology is a mapping consisting of two components: links and nodes. In general, each component in the mapping is described in terms of its capacity, average cost and average travel time. Furthermore, these parameters shall be distinguished in terms of passenger and freight service. This mapping ultimately shall be expressed for some horizon-year (which we tentatively assume to be 1990), but may be decomposed into a staging by, say, five-year increments. Thus, the basic set of policy variables includes capacity and service attributes, specified in broad terms of location and timing. Location is defined by the abstract network, which aggregates the real-world transportation network into a system of interconnected "corridors."

In defining an appropriate span of control for the proposed planning effort, however, a mere articulation of

the "abstract network" and "network parameters" concepts is not adequate. While we have established our descriptive definition of a "master plan," we have yet to indicate the manner in which such a plan might be used to aid decision-making. Three types of interface merit consideration in this respect: (a) that between private and public enterprise in transportation; (b) that between transportation planning and other Statewide planning activities; and (c) the relationship between this Statewide master plan and its amplification by local and regional planning and engineering efforts.* Each of these proposed relationships is given brief discussion below.

## 2. Public vs. Private Enterprise

The master plan would depict a "good" (vis-a-vis "optimal") Statewide transportation system -- in skeleton form -- for the horizon-year, taking the existing system as given. This plan would serve as a guide for public investment in new transportation facilities; such decisions will be the most important ones which PennDOT faces.

Obviously, private enterprise also invests in transportation facilities, and the future pattern of such investment will not necessarily be in accord with the master plan. To the extent that the Commonwealth has regulatory authority over such proposals from the private sector, be it direct

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* This third consideration serves to define the appropriate areal granularity for the methodology's traffic analysis zones, to be explained shortly.

authority or indirect influence as a very interested party in Federal hearings, the master plan will have a very definite role in guiding the Commonwealth's policies. Presumably any large undertaking by the private sector (such as the development of a new mode) will be subject at least to Federal regulation; the Civil Aeronautics Board offers a strong precedent. To the extent that private initiative in extending the Commonwealth's future transportation system is not "guidable" by PennDOT, revisions in the master plan may become necessary if those extensions are major ones.*

### 3. Coordination With Other Statewide Planning

Interface between the planning activities of PennDOT and other Statewide planning activities is encouraged strongly by our methodological design. While we assume that PennDOT's policy-making responsibility shall be restricted to transportation, we provide a mechanism by which PennDOT's Statewide planning will be sensitive to other Statewide plans, such as those envisaged by the State Planning Board (see chapter IV).

Specifically, our forecasting model system includes an econometric model which is sensitive to induced changes in socioeconomic activity, be they accomplished through direct government procurement, vocational training, recreational

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* Our point here is merely one of flexibility. We do not intend an endorsement of either more or less regulation of the transportation industry.

development, flood plain control, or whatever.* Furthermore, the impacts of such policies upon future travel patterns can be assessed. Moreover, the process of fashioning alternative plans is designed to weigh some areas of the State more heavily than others, if such a policy is articulated.

4. Proper Amplification of the Master Plan

In chapter V considerable attention was given to the proper relationship between the Statewide master plan and its amplification by local and regional planning and engineering efforts. As discussed in both chapters IV and V, a major controversy has developed in the transportation field regarding the role of long-range transportation planning studies insofar as specific facility detail is concerned.

Put briefly (and quite objectively), highway engineers have tended to expect urban transportation planning studies to produce design volumes for detailed facilities such as freeway ramps. The urban studies (which have been very highway-oriented) have responded by defining their abstract networks to a level of detail much greater than is reasonable for long-range planning of regional network configurations.

We refuse to follow this urban planning precedent, and we think the root of the controversy lies in a misconception of what long-range transportation planning really is. Our

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* If the State Planning Board can provide estimates of the direct impact of such policies upon local socio-economic activity, the econometric model can trace the indirect impacts of these changes throughout the State's economy.

methodology is concerned with developing a master plan which is accommodative of anticipated long-range travel patterns and of Statewide development policy. Quite bluntly, this concept is very remote from the daily activities of the highway engineer, and under no circumstances is a very detailed system of traffic analysis zones called for. Considering the inherent tradeoffs in statistical analysis between areal detail and detail on trip characteristics, we believe the concern of this Statewide planning activity should restrict itself to the Edwards and Kelcey state zone system (149 areal units).

In taking this strong position, we hardly intend to neglect the importance of engineering design. Accordingly, we have provided for a direct tie between the Statewide comprehensive methodology recommended herein and the amplification of the master plan at the local and regional level. Indeed, we believe that the regional analysis approach contemplated by the Bureau of Advance Planning in the Department of Highways is the proper vehicle for such amplification. Guidelines for this interface are given in later chapters.

## B. Relevant Effect Variables

As discussed in chapter II, a general principle of planning is that a set of goals or objectives should be established at the very outset of a planning effort. Goal specification has been extremely nebulous in practically all large-scale transportation studies. To the extent that any objective is followed, it has been the rather narrow one of minimizing total dollar costs (capital, maintenance, and

operating*). Except for this sort of engineering economics approach, no objectives for transportation or for any other planning activities in the Commonwealth have been articulated, to our knowledge.

Goals for transportation and any other planning activity have two aspects: the identification of relevant decision criteria and the assignment of relative weights to each. In lieu of such weights, one criterion (or a weighted combination of several criteria) might be singled out to be maximized, subject to prespecified constraints upon all other relevant criteria. Essentially, the first aspect suggests what measurements should be made by the planning effort, while the second indicates what factors should govern the evolution of alternative transportation plans. Because transportation is a socially oriented system, the second aspect is extremely difficult to capture.

Society is believed to have a hierarchy of goals in which one goal, while an end for a particular objective, is a means of attaining another objective.** That is, goals and constraints are interchanged at different levels of decision-making in the political process. Since there is rarely complete agreement on goals, the differential effect of participants (legislators, lobbyists and other pressure groups) depends on the resources each represents, and goals

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* including rather arbitrary dollar valuations of travel time

**Objectives are defined as operational or measurable goal indicators, or subgoals, which serve as surrogates to goals.

are implicitly formed by mediation among the goals of participants. This arbitrage process is not understood very well, but it is not believed to be systematic, particularly where more than a few criteria are involved.

### 1. The "Informal Dialogue" Approach

One approach to this problem is simply to define relevant criteria, estimate the performance of alternative plans in terms of these criteria, and place the issue of weighting criteria entirely in the lap of the political process. Relevant criteria would be determined on the basis of planning expertise as a minimum, and hopefully on at least some informal dialogue with selected decision-makers (e.g., a special legislative committee).

The price of this approach is quite clear. Only a limited number of alternative plans can be generated within the planning process. Without any preliminary notions of relative weights, a great number of alternative plans would have to be generated in order to present an adequate mixture of emphasis on the different criteria. To the extent that preliminary notions of relative importance can be gleaned, the range of alternatives to be covered by the planning effort is reduced. As a simple example, knowing roughly the importance of developing existing urban centers versus promoting the depressed rural areas of the Appalachian belt clearly would reduce the variety of network configurations to be considered.

## 2. The "Formal Dialogue" Approach

An alternative approach which some believe to hold promise involves a more formal dialogue with selected decision-makers, using analytical methods for determining relative weights (either ordinal or cardinal). These techniques have in common a procedure in which participants are presented with a comprehensive list of goals, objectives, or program attributes, and are requested to make pairwise comparisons of elements on the list.

The actual method used would vary in complexity and depend on the level of expertise of the participants. It could involve either a simple choice, or a choice stating the relative magnitude of preference. In the first case only a ranking would result, whereas in the second case it would be possible to state the magnitude of the difference between ranked items. The procedure is repeated until all combinations are exhausted, and hence until the items are ranked and weighted. Weights are then normalized.* Logic errors are eliminated by a final step consisting of systematic sub-group comparisons. This type of procedure is systematically repeated until all relevant sub-groups are compared. A logical rating of items, on a relative basis, is thereby achieved.

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* For example, if the highest ranked item is considered more important than all other items combined, then the normalized weight of that item should be greater than or equal to one-hal

## 3. Recommendations

Our position favors the simpler approach, whereby relevant criteria are identified on the basis of planning expertise, and informal dialogue with some form of legislative committee is pursued. In choosing this course of action, we hardly intend to deny the potential which analytical rating techniques can offer. They have been implemented in one form or another by several large corporations and by the U.S. Department of Defense. Until such techniques become more popular in other political contexts (which implies that some strong prejudices against "the numbers game" must be overcome), we feel PennDOT should limit its liasion with decision-makers to an informal basis. As will become evident later, our methodological design is very forward-thinking in many respects; on this point, however, we have deliberately avoided any unprecedented sophistication.

As suggested in chapter V, the PennDOT methodological design is predicated on the position that the indirect impacts of Statewide transportation policy upon socioeconomic activity are just as relevant as direct effects upon system users. This position is prerequisite to a comprehensive approach in the sense that transportation is a very meaningful instrument for shaping Statewide development as well as a means for increasing mobility per se.

Direct effects to be considered in the methodology include all user sacrifices which are readily quantifiable. While the generalized concept of "impedance" discussed in chapter II includes out-of-pocket costs, travel time,

reliability (e.g., meeting of schedules, accident rates), discomfort and inconvenience, by and large the methodology will focus only upon the cost and travel time components, for two reasons. First, the other components are much more difficult to measure. Second, only the cost and travel time are effectively discriminating, in the sense that the other measures tend to vary only very slightly between alternative transportation systems. These two items shall be measured separately for both passenger and freight service, and shall be summarized over all links and nodes to indicate total system impact upon users. Pending further research on intercity mode choice, for both passenger and freight transportation, we do not recommend that a dollar value be imputed to travel time. Such numbers are yet too arbitrary to permit a meaningful dollar conversion.

Indirect effects to be considered by the methodology include classical measures of socioeconomic activity, quoted both for the entire State and for its subareas (counties). These include gross output (in dollars and tons) and employment by industrial sector, population, and personal income. We emphasize the importance of quoting these measures -- as they are affected by Statewide transportation policy -- in terms of their locational and industry-specific incidence, for the benefit of legislators, lobbyists and other pressure groups. These interests must be accommodated; otherwise the planning effort may require substantial repetition in response to their desires for more information.

All of these direct and indirect effect variables represent the "relevant evaluation criteria" we recommend for PennDOT's comprehensive planning methodology. On no account do we intend to define the relative importance of each variable. In other words, we are opposed to the idea of defining rigorously structured goals for the planning efforts. Preliminary dialogue with decision-makers is encouraged in order to establish very crudely what factors they might tend to use.

## C. Data Requirements

In a previously cited memorandum to Governor Shafer,* Chairman Hazard identified "the maintenance of a data bank on all aspects of transportation in the State" as one of the three key functions of the proposed Department of Transportation. He also emphasized the fundamental importance of establishing what information currently is available for synthesis into such a data bank:

> At the present time there is no known repository of information or data relative to the total transportation system that would aid the Committee in their deliberations. Yet such information is essential as a guide to the establishment of the structure and function of a Department of Transportation.

Accordingly, a very comprehensive synthesis of existing

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* See "Design for a Pennsylvania Department of Transportation," Commonwealth of Pennsylvania, Governor's Committee for Transportation, February 1968; p. 24.

transportation data has been completed per TAC Operational Project No. 4.*

## 1. General Observations

This remarkably thorough synthesis, together with our own supplementary investigations of available transportation and socioeconomic data, prompts a conclusion which was hardly unanticipated: existing data are quite inadequate for a truly comprehensive transportation planning methodology. Particularly glaring deficiencies include: (a) freight flows by all modes (except air**); (b) passenger flows by the bus mode and, to some extent, by the rail mode; (c) access flow patterns of passengers for all non-highway modes; and (d) interindustrial structure.

As stressed repeatedly in prior chapters, the fundamental theme of this report is that information requirements have been considered integrally with analytical planning techniques in this methodological design. The purpose of this section is to structure the requisite data processing effort associated with the methodology recommended in

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* Wilbur Smith and Associates, Project 4: Inventory and Adequacy of Existing Statewide Transportation Systems, preliminary draft, prepared for Technical Advisory Committee, Governor's Committee for Transportation, Commonwealth of Pennsylvania, January 1968.

**Given its resource limitations, the Infrastructure Survey synthesized by Wilbur Smith and Associates (and subcontractors) generally avoided any "raw" data collection. However, that effort did include a survey of commercial airlines to determine origin-destination patterns of commodity flows by the air mode (a very valuable bank of information).

succeeding chapters, and to point out additional survey work which must be done.

In referring to data requirements, we mean information which is necessary for implementing a "comprehensive" transportation planning methodology. By "comprehensive," three key characteristics are inferred. First, all modes of transport, for both passenger and freight movements, must be considered. Second, the methodology must consider the impacts which Statewide transportation policy will have upon patterns of socio-economic activity. Third, transportation planning can be much more meaningful if it analyzes travel patterns in terms of the entire trip or journey from ultimate origin to ultimate destination.* All of these criteria are derived directly from the discussion of salient issues in chapter V.

The aforementioned gaps in passenger flow data, plus a nearly complete ignorance of all economic transactions between industries in the Commonwealth, indicate quite bluntly how remote we are from meeting these "comprehensive" standards. Of all issues uncovered by this study, one must be faced most squarely: very substantial survey work is an insubstitutable prerequisite for comprehensive Statewide transportation planning. The methodological designs for both Connecticut

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* The implication here is twofold. To state that the origin-destination concept is vital to the analysis is to argue that aggregate statistics of transportation activity for the entire Commonwealth or for individual points in the State are of little value for planning spatial network configurations. In addition, origin-destination data from airport to airport (for example) ignore important terminal access components of an entire journey.

and California reached the same conclusions*; other states most certainly will face the same problem in the future. The longer these states delay such survey work, the higher their burden of total social cost will be, as discussed in chapter V.

The remainder of this section elaborates upon the data requirements of the proposed PennDOT methodology. A rather simple taxonomy for structuring the discussion is provided by the following trichotomy of transportation planning data:

1. Socioeconomic activity
2. Network characteristics
3. Network utilization patterns.

The forecasting model system involves two general types of interrelationships between these three categories of data. The estimation of indirect effects (by means of the Econometric Model**) characterizes the intensity and the spatial distribution of socioeconomic activity as a function of network characteristics (primarily transport costs), in terms of structural interdependencies between sectors of economic (and demographic) activity. The estimation of direct effects characterizes network utilization patterns (passenger and freight flows) as a function of socioeconomic activity (by traffic zone) and network characteristics (costs, transit or travel

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* To emphasize that such conclusions are not merely flamboyant verbalisms, note that the Connecticut Interregional Planning Program already has conducted statewide surveys of passenger travel and goods movements, of recreation facilities and participation patterns, and of community goals and objectives.

**See the following section.

times, and scheduled frequencies). The specific requirements of the methodology in terms of each category are outlined below. Further details are given in individual chapters to follow.

## 2. Socioeconomic Activity

Data on socioeconomic activity are required for three purposes: (a) the estimation of passenger travel demand; (b) the estimation of commodity flows; and (c) a meaningful impact analysis which traces the effects of transportation policy throughout the complex structure of the Commonwealth's economy. Each purpose dictates certain requirements in terms of the character of socioeconomic data and the areal granularity at which such data must be quoted.

The analysis of passenger travel patterns (see Chapter XIII) requires measures of population, personal income and employment (by one-digit SIC*) for some system of contiguous areal units exhausting the Commonwealth and its relevant periphery. Existing origin-destination data for passenger transport are referenced to different zone systems (see the Infrastructure Survey report) involving different degrees of areal aggregation varying with each mode. The highway mode, being most detailed, most govern. Thus, the aforementioned variables must be quoted, for some base year,** in terms of

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* Standard Industrial Classification Manual, U.S. Bureau of the Budget, Washington, 1957.

**The final selection of a most appropriate base year is left for later analysis. No matter what year is chosen, various sources will have to be reconciled to a common year. The forthcoming 1968 Census of Transportation and the 1970 Population Census (both to be conducted by the U.S. Bureau of the Census) should be taken into consideration, too, in this decision. In any event, the objective is to establish one time period for calibrating the forecasting model system by cross-sectional empirical analysis (see Chapter II).

the Edwards and Kelcey traffic zone system. This information can be obtained from the Edwards and Kelcey reports, supplemented by additional analysis based on the County Business Patterns publications of the Bureau of the Census.

The analysis of O-D patterns for commodity transportation* will require considerably less areal detail than the zone system used in the Edwards and Kelcey study. This is so primarily because the average length of haul for freight movements is substantially greater than the mean trip length of passenger travel. The precise areal unit system for freight analysis is not defined here, pending a preliminary regionalization of the State (and its relevant periphery) based upon available county economic data. The number of areal units or "nodes" anticipated (aggregations of counties) will fall within a range between fifteen and forty. Specific measures required for the freight movements analysis include dollar output and tonnage output (and imputed prices at-the-origin) by two-digit SIC or some reasonable aggregation thereof.

To a great extent, such data for individual counties in the Commonwealth and surrounding states are readily available from Federal publications described in chapter V. However, no information on interindustrial relationships is available, except for the Philadelphia input-output study.** The need

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* This task will be handled by the Econometric Model (see chapter VII) and the Freight Modal Split Model (see chapter VIII).

**Isard, W., Langford, T.W., Jr. and Romanoff, E., "Philadelphia Region Input-Output Study," Regional Science Research Institute, Philadelphia, undated.

for this character of information is quite clear: the sensitivity of Pennsylvania's economy to transportation can be captured only in terms of the structural relationships between industries which serve as shippers and consignees to one another. Unless we assume that industrial production functions in the Philadelphia region are representative of the entire State, then, a special survey of industrial firms is required. As will be discussed below, a freight movements survey is required in any event. The marginal costs of procuring information on interindustrial relationships would be small, given the investment in a commodity flows survey.

### 3. Network Characteristics

The second category of data, i.e., "network characteristics," refers to the capacity and service attributes of links and nodes in the "abstract network" (see chapter II), described separately for passenger and freight transportation. Elaborative definition of the abstract network concept for the Commonwealth is reserved for chapter IX; our concern here is with the character of network measures desired.

Briefly, requisite data of this category include average costs (or fares) and average times occasioned by all persons for each link and node of each passenger mode, and average rates and times occasioned by various commodity groups for each link and node of each freight mode. Scheduled frequencies for each O-D pair, for passenger modes and for freight modes, are also required. Using the Infrastructure Survey report, together with further examination of published

schedules and of typical motor vehicle use surveys, all of the passenger network characteristics are readily derivable. The freight network information would be measured in the special survey of interindustrial economic transactions.

### 4. Network Utilization Patterns

This third category of data refers to tabulations of traffic flows in accordance with the abstract network defined for a transportation planning effort. Two types of utilization data are required. As emphasized earlier, information on origin-destination patterns for all interzonal passenger and freight journeys is required. The other requirement refers to the manner in which these flows are allocated over series of links (and nodes) in the network. The point simply is that a given O-D flow generally involves more than one link, and the various links in a route may involve different modes.

The state of network utilization data for the Commonwealth is roughly as follows. The only type of traffic for which origin-destination data include the <u>entire</u> journey is automobile travel. A companion set of link flows also is available only for this mode. All other origin-destination data, whether for passenger traffic or for freight movements (for which we have only shipments by air), represent statistics only on <u>part</u> of an entire O-D flow since they ignore access characteristics at both terminals of the flow. Aside from this point, the overall picture of available utilization data is illustrated in Tables VI-1 and VI-2, which are based on the Infrastructure Survey.

The purist's attitude here would call for an entire set of passenger and commodity surveys, involving interviews of households and firms respectively, since only such an approach would give us a bank of data on total journeys including all intermodal transfers. Our point of view toward commodity flows is no less purist. However, the amount of data available on passenger traffic (be it less than complete) is sufficient that a few small-scale surveys will fill all gaps adequately.*

The circled entries in Table VI-1 indicate areas in which such small-scale passenger surveys are required. They include O-D and link flows for bus transportation and link flows for rail. In addition, surveys are required of all non-highway passenger transportation modes to determine access patterns.** All passenger data shall be referenced to the Edwards and Kelcey traffic zone system.

The very critical gap, of course, is in commodity origin-destination data (see Table VI-2). Except for the air mode, any existing data are very limited and statistically very unsatisfactory. Without a large-scale commodity transportation survey, the analysis of freight transportation can be improved negligibly beyond the efforts of TAC Operational Project No. 5.***

* No stratification of passenger travel by trip purpose will be possible under these circumstances.

** The Department of Highways has already initiated an analysis of access times to and from the Greater Pittsburgh Airport in conjunction with the Southwestern Pennsylvania Regional Planning Commission.

***This conclusion was reached only after very serious consideration of petitioning the Bureau of the Census for special tabulations of their Census of Transportation's Commodity Transportation Survey. Their samples are too small for the level of detail required here.

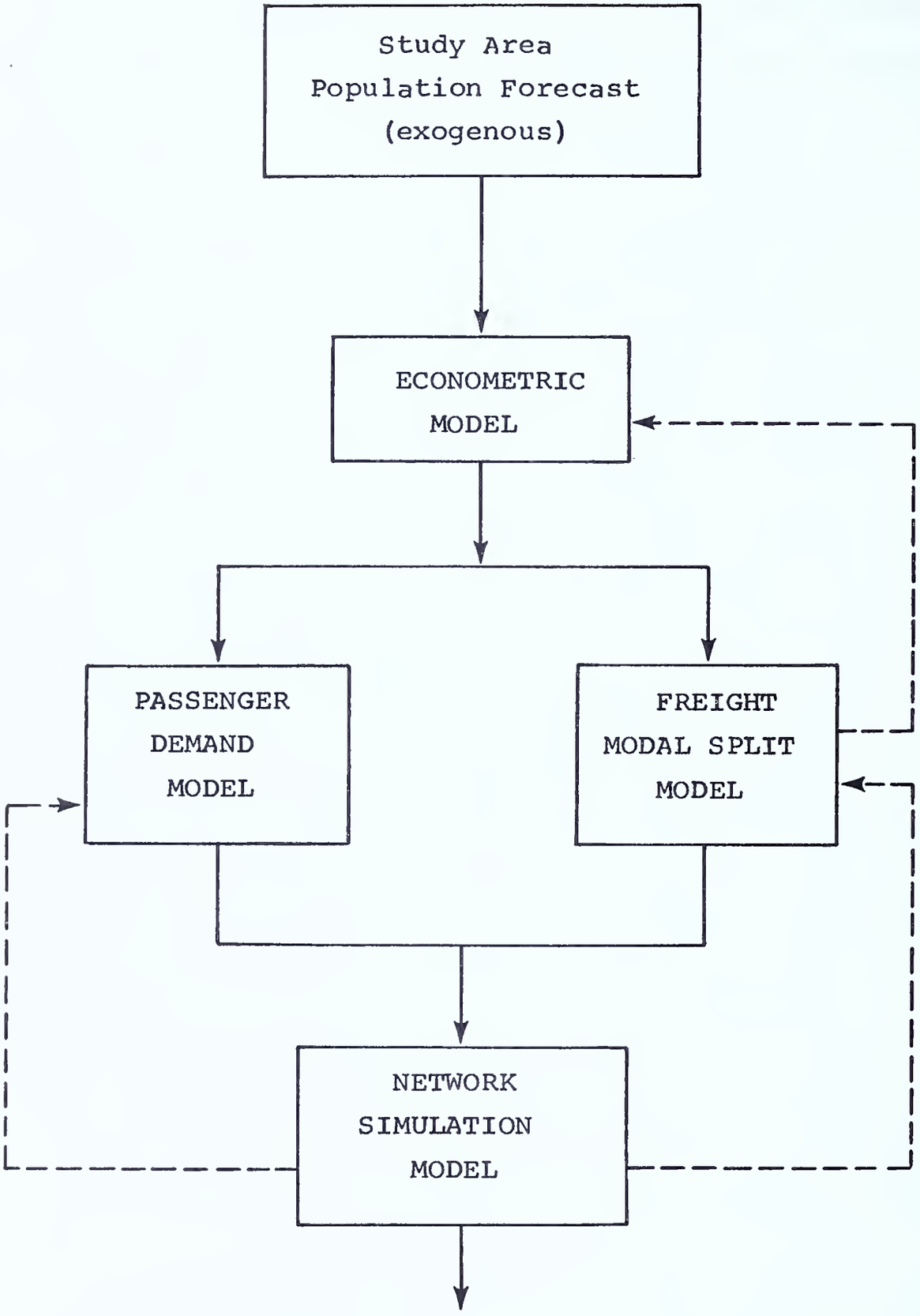


Figure VI-1. Outline of the Forecasting Model System

## 5. Summary

The preceding discussion has pointed out the need for additional data collection in each of the three fundamental categories of relevant information, in reference to several explicit criteria for "comprehensive" planning. In summarizing that discussion, we merely wish to emphasize further the need for a thorough survey of interindustrial interregional transactions in the Commonwealth. This survey would fulfill the very critical pressure for a comprehensive bank of commodity flow information and, at little marginal cost, would provide the analytical insight which we feel is so vital for the estimation of indirect impacts upon socioeconomic activity. While details of the survey are given in the following chapter, it will be quite similar to the original survey format employed in the Philadelphia region's input-output study cited earlier.

Finally, we also wish to emphasize that PennDOT hardly will be the sole beneficiary of such comprehensive information. At a time when most other states are just catching on to a relatively unsophisticated transportation methodology, this survey and its primary processor (the Econometric Model) will give Pennsylvania a comprehensive tool for evaluating integrally many avenues of its public policy. In sum, we believe this investment in information is perhaps the most important step to be taken toward the long-run economic development of the Commonwealth.

| PASSENGER TRANSPORTATION | AUTO | BUS | AIR | RAIL |
|---|---|---|---|---|
| O-D FLOWS | YES | NO | YES | PARTIALLY* |
| LINK FLOWS | YES | NO | YES | NO |

* I.e., for a select subset of O-D pairs.

Table VI-1. Availability of Passenger Network Utilization Data

| FREIGHT TRANSPORTATION | TRUCK | RAIL | WATER | AIR | PIPELINE |
|---|---|---|---|---|---|
| O-D FLOWS | PARTIALLY* | NO | NO | YES | NO |
| LINK FLOWS | PARTIALLY** | YES | YES | NO | YES |

* O-D freight flows are required in terms of tonnage. The Statewide O & D Survey measured flows only in terms of number of vehicles. The Loadometer Study measured tonnage flows, but the results are very inconsistent.

** The Department of Highways Road Log reports link flows in terms of number of commercial vehicles.

Table VI-2. Availability of Freight Network Utilization Data

## D. The Forecasting Model System

The core of the entire methodological design is the forecasting model system, the purpose of which is to predict the expected direct and indirect effects of any hypothesized Statewide transportation plan. Besides this sensitivity to transportation policy, flexibility for planned land use inputs is also provided. This model system consists of four major components (see Figure VI-1): the Econometric Model, the Freight Modal Split Model, the Passenger Demand Model and the Network Simulation Model. Operation of the entire model system is initiated by exogenously prepared forecasts of horizon-year population for the study area (Pennsylvania and its periphery).

The Econometric Model estimates the intensity and spatial distribution of socioeconomic activity associated with the given population projections and a hypothesized future transportation network (expressed in terms of the policy variables discussed above). A basic assumption of the design is that the sensitivity of industrial activity and location in the study area is predominantly oriented to freight rather than passenger transportation service. In order to trace as thoroughly as possible the multiplier effect of transportation impacts as they propagate throughout the economy, this sensitivity is couched within the framework of interindustrial structural relationships to be defined by extensive survey work. This characterization of interindustrial transaction patterns is developed in such a manner that the model simultaneously estimates interzonal commodity flows (a subset of

all relevant direct effects). The design of the Econometric Model is detailed in the following chapter.

The remaining three models deal strictly with direct effects. The Freight Modal Split Model and the Passenger Demand Model (see chapter VIII) operate in parallel to estimate the expected origin-destination patterns of each freight and passenger mode respectively. Both of these models characterize alternative modes in terms of their cost-service parameters, thereby abstracting their attributes from their specific physical characteristics. Only by such an abstract approach can the market response to new modes be assessed reliably. The Freight Modal Split Model is restricted to the analysis of mode choice patterns elicited by shippers, the origin-destination patterns of commodities having been determined by the Econometric Model. On the other hand, the Passenger Demand Model treats integrally the trip generation, distribution and modal split phases which have always been addressed separately in traditional transportation planning methodology. The passenger model's inputs from the Econometric Model consist of those socioeconomic variables, for each zone, which are hypothesized to explain travel behavior (e.g., population, personal income, employment). This integration of the three phases into one model, along with the simultaneous approach taken in the Econometric Model, is prompted by the conviction that decisions of firms and households which tend to be made simultaneously should be analyzed simultaneously.

The Network Simulation Model (see chapter IX) receives as input the forecasted origin-destination flows for each

freight and passenger mode and allocates this traffic to determine loadings on specific network components. Its primary concern is with route choice patterns. Naturally, it has a strong orientation to the State's highway system since the range of alternative routes offered by that system is considerably broader than for non-highway transport. To the extent that individual network components are utilized close to or in excess of their capacities, the reallocation of flows to alternative routes and/or modes is accomplished iteratively until an equilibrium solution is converged upon. The reallocation to alternative modes is represented in Figure VI-1 by the feedback paths to the two prior models. These and other feedback operations, plus a variety of conversion procedures required to knit the four models together, are given detailed elaboration in chapter X.

## E. The Total Planning Process

In the transportation planning field, there is a strong tendency to dwell upon the design of a forecasting model system and to slight the methodology involved in using the model system for planning purposes. However, the whole idea behind the model system is its ultimate application to test a broad range of alternative plans, as suggested by tasks 5, 6 and 7 in the sequence of planning steps listed at the beginning of the chapter. Task 5 refers to the process of fashioning alternative plans and task 7 involves the evaluation of those alternatives; the application of the forecasting model system links these two endeavors so as to allow an iterative search process for a range of "good"

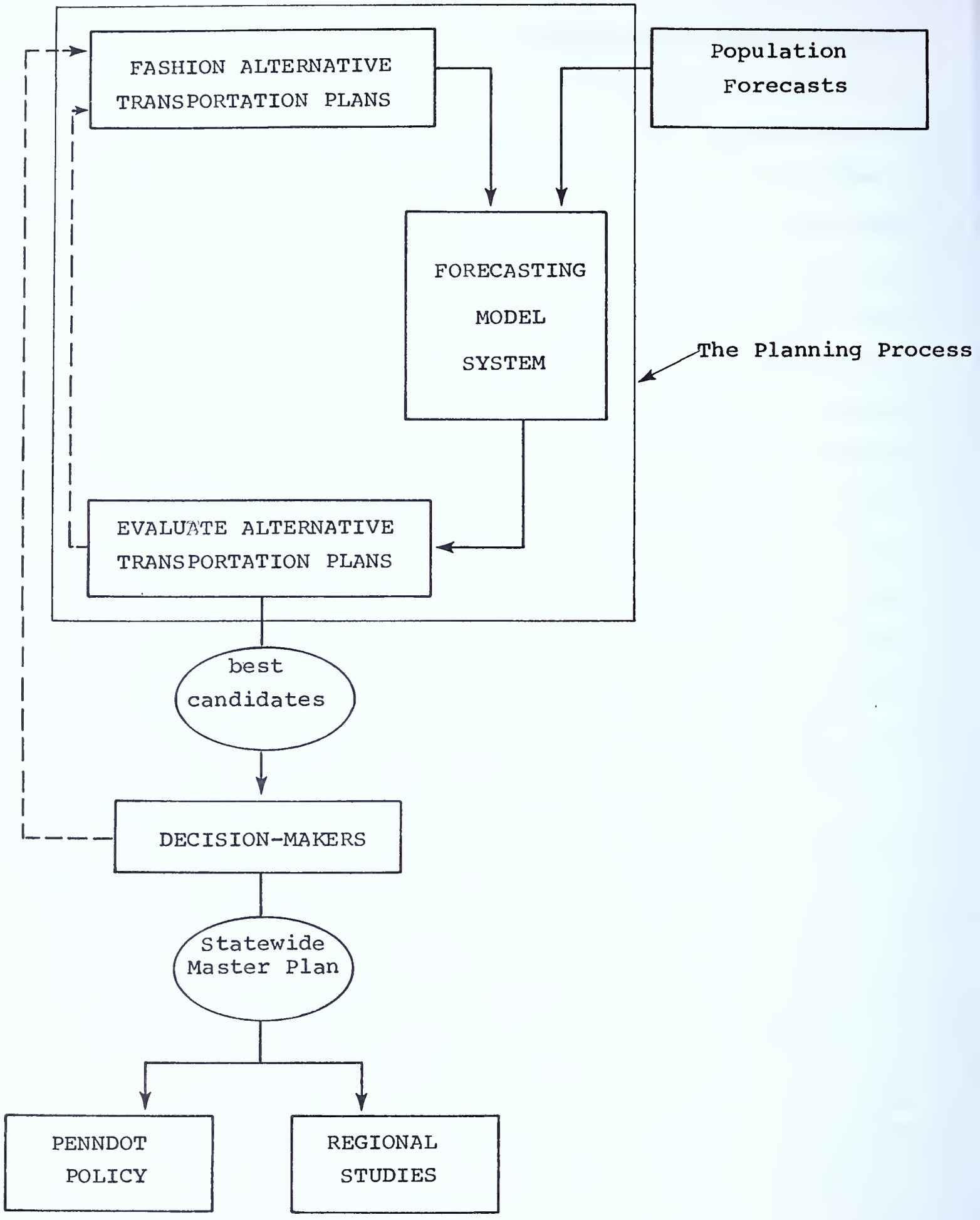


Figure VI-2. The Integrated Statewide Transportation Planning Process

candidates.* These candidates are then submitted to decision-makers for their selection of one as a long-range master transportation plan for the Commonwealth (perhaps after some feedback for either more information on the presented candidates or generation of revised candidates). Given such adoption, regional planning efforts can proceed to use the master plan as a guide to their solutions. This broad perspective is depicted in Figure VI-2.

The scope of the PennDOT design includes the operations of fashioning alternative systems and evaluating them within the Statewide planning process of PennDOT. We deliberately refrain from proposing guidelines for final evaluation by policy-makers. The methodology to be followed by the regional studies shall be worked out by PennDOT in cooperation with local agencies.**

The methodology proposed for fashioning and evaluating alternatives within the entire planning process takes advantage of recent research conducted for the Illinois Division of Highways, which represents one of the precious few attempts to objectivize the system design process. The technique is highway-oriented, and, pending further research, leaves the formulation of non-highway improvements to the planner's intuition as expressed with a grease pencil and a map. The

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* Recall from chapter V that the capability for selecting an "optimal" transportation network does not exist.

**We emphasize here the importance of PennDOT's involvement in these regional studies, since the State will have quite an interest in their planning decisions.

strategy adapts concepts of "multivariate discriminant analysis" (the parlance of the theoretical statistician) to the link classification problem which is so familiar to state highway departments. It is very intimately tied to the forecasting model system, in that it (a) groups highway network links on the basis of similar expected volume and functional characteristics, (b) calls for the assignment of a level of service to each group of links (as expressed by capacity and speed parameters), and then (c) submits that highway network description to the forecasting model system for testing. This entire process is repeated in iterative fashion whereby service levels are revised and evaluated. The technique also permits the deliberate distortion of results to weight some areas of the Commonwealth more than others, thereby reflecting alternative State development patterns. This total planning strategy, along with a detailed synthesis of the forecasting model system's major and minor components, is given elaboration in chapter X.

# VII
# THE ECONOMETRIC MODEL

## A. Introduction

As explained in the previous chapter, the Econometric Model has a dual function as part of the forecasting model system. One purpose is to estimate the impact of transportation policy upon the intensity and spatial distribution of socioeconomic activity within the study area. Secondly, it simultaneously estimates the origin-destination pattern of commodity flows for the study area.* This simultaneous analysis of freight flows is based on the proposition that, for a study area as large as ours, the relevant transport-sensitivity of socioeconomic activity is primarily related to freight service rather than passenger service. Industrial firms tend to locate near other industrial firms in accordance with interindustrial interdependencies characterized by the "production function." The proximity of one industry to another is meaningful only in terms of freight service. Passenger transportation characteristics are of second-order importance, and enter the model only in the location of the labor-producing population.

The demand for transportation is a derived demand. The flow of commodities exists because production and consumption do not occur at the same time and place. There are different

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* As discussed earlier, this model shall also be readily applicable for statewide economic planning by the State Planning Board.

kinds of commodity flows, such as:

(a) flows of primary products to factories, processors and other users;

(b) flows of intermediate goods among factories and processors; and

(c) flows of goods from factories and processors to final users.

In addition to the above three flows, there exists a corresponding set of intermediate flows into and out of storage. This storage occurs in stockpiling, warehousing, wholesaling and retailing activities.

The character of the commodity flows of any region depends on the characteristics of the producers and consumers of the commodities and on their spatial distribution. Since every producer and consumer will require many commodities from various sources, the flow of these commodities becomes extremely complex, and any change in the socioeconomic character of the region will change the pattern of the flow.

The flow of commodities is accomplished by the transportation system, which must be sufficiently versatile to provide the specific service requirements associated with the movement of any commodity. If all commodities were shipped in units of the same shape, size and weight, there would be little need for versatility in the transportation system. The growing importance of "containerization" results from the costs involved in maintaining a highly versatile transportation system. The extreme complexity of the rate structure also is due, in part, to unique transportation requirements associated with each commodity classification.

The various modes of transportation employed in the complex movement of commodities are perhaps best differentiated in terms of their cost structures in relation to the spectrum of transportation services they provide. And since firms will tend to minimize their costs for any given service, the pattern of modal use throughout a region will tend to correspond to the pattern of commodity flows. In other words, the demand for various types of transportation services will depend on the specific mix of commodities for which the services are required. Thus, any attempt to forecast transportation needs for a region must be based on anticipated flows of different commodities throughout the region.

## B. The Leontief Input-Output Model

The most promising tool of analysis for a freight transportation forecasting model involves the adaptation of a Leontief type input-output table.* With this technique, economic data for some base year are arranged in a table so as to reveal the interzonal interindustry flows of goods by some commodity classification. The table is thus a kind of dated "still" picture of the interrelationships among zones and industries.

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* The classical Leontief model represents a tool of analysis for one region (Leontief, W., The Structure of the American Economy: 1919-1939, Oxford University Press, New York, 1951). The multiregional or interzonal concepts discussed hence refer to an extended class of models (see Isard, W., Methods of Regional Analysis, M.I.T. Press, 1960, Chapter XII).

Final demand for consumer goods is considered to be determined by outside forces. Regions and industries usually are assumed to behave like firms having constant returns to scale. On the strength of these assumptions the input-output data for the base year are used to derive a set of technological coefficients that describe the relationships of inputs to outputs of all regions and industries. If these coefficients are assumed to be constant, then the model can be used to compute a completely new set of data that would be a forecast of the interzonal interindustry flows of commodities that would result from a change in the final demand for consumer goods.

This type of model captures the highly complex set of interrelationships among industries and regions and is thus a powerful tool, particularly well suited for transportation systems analysis. There are no theoretical limits to the capacity of the model to represent any detail of breakdown by region or commodity. However, practical limits do exist. These limits are of two main categories. The first is associated with the capacities of data processing equipment. The second is related to the cost of obtaining data for the model.

Technological advancement in the field of high-speed electronic digital computers is rapidly narrowing the gap between our needs and our capacities to handle large systems and masses of data. Already we are able to handle systems involving many hundreds, and even thousands, of simultaneous

equations. Thus computational capacity is available now for handling the requirements of a transportation model involving enough detail to be of practical value.

The high cost of obtaining detailed information for a fine breakdown of interregional flows of commodities remains with us. However, it is becoming increasingly apparent that in our complex society the cost of errors resulting from bad planning are far greater than the cost of avoiding them by establishing a reliable factual basis for both private and public planning. Much of the detailed information needed for a useful transportation model is precisely the information needed for other planning purposes. Besides, the input-output approach is sufficiently general to serve the purposes of other planning agencies.

The usefulness of the input-output type model in a systems approach to various kinds of planning has gained rather wide acceptance. However, there is scope for improvement in the precise form and assumptions of the model. The form and method of application proposed here have been developed with a view to removing two of the most serious limitations of the method. The first has to do with the assumption of constant technological coefficients, the second with the lack of complete transportation sensitivity. That is, this type of a model has not been able to forecast satisfactorily the impact of changes in transportation costs and capacities on regional development and commodity flows.

We assume that the more important centers of economic activity in the State have been identified and that the

State is subdivided exhaustively into a set of economic regions where each region contains one and only one of these centers.* Attention to the transportation needs of Pennsylvania, for the purpose of this model, is confined to the flow of commodities into and out of each of these regions, and not with transportation within any of these regions. Since the flow of goods to and from the regions of Pennsylvania includes flows to and from points outside the State, it is necessary for the model to identify traffic movements to centers of economic activity in other areas of the U.S.A. and of the rest of the world. We define a "node" as the center of economic activity of a region and assume that all commodity flows are to and from these nodes.

The Pennsylvania transportation system must provide the means by which the inter-nodal flow of goods may be accomplished. A rational plan for the expansion of transportation facilities must be based on expectations as to what the future flows of commodities will be.

There exists a considerable body of literature that describes the Leontief type input-output model. Only the essential features will be presented here. The commodity flows among regions and industries are the basic elements of the model. These flows are represented in Table VII-1 where, for illustrative purposes, all productive activity takes place in three industries located in the same region.

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* See section I of this chapter.

It is apparent from Table VII-1 that the total output of each industry is absorbed completely by all industries and government taken together. This representation is quite realistic if industries are defined to include households. In this illustration, for simplicity, government activity is not considered productive of any inputs into industries. It is also apparent from Table VII-1 that while each row may be summed to provide the total output of each industry, it is quite meaningless to sum the columns which consist of numbers with different dimensions.

If prices for the various products are given, it is possible to convert the data in Table VII-1 to corresponding money flows. This is done in Table VII-2, where the prices used are $1, $5, and $10 per unit for the products of industries I, II and III respectively. In Table VII-2 column sums are now listed, providing the total costs of resources used by government and each industry. The totals of the rows are now the total revenues. Table VII-1 may give a complete picture of the flow of goods and services into and out of all commodity producing sectors of the economy. Table VII-2 will give the corresponding money flows involved in the flows pictured in Table VII-1; however, Table VII-2 will not be a complete picture of all the money flows involved in the activities of these sectors. For example, tax and interest payments would be excluded since these are not directly involved in the production activities of the various industries. For this reason, the total revenue of any industry need not be equal to its total cost.

Table VII-2 could be expanded to include all money flows into and out of each industry, and this is done in the typical Leontief type table. In order to achieve this, the table must be made to include strictly financial transactions. For purposes of the model needed for estimating transportation requirements, it would be sufficient to limit the table to the kinds of money flows described in Table VII-2; however, for more general purposes, it would be desirable to have the complete money flows described by the full Leontief type input-output table. If the full table is available (for some given base year), it may be partitioned so as to give the part needed for the transportation model.

In Table VII-2, a final row below the Total Costs now has been added and labeled "Differences". It is the difference between Total Revenue and Total Cost and is, therefore, a kind of gross profit or value added figure. The entries in this row would account for tax and interest payments, undistributed profits, etc. It is apparent from the above that for every industry: Total Revenue - Difference = Total Cost. This relationship will be used in the analysis of the model to be developed.

## C. The Econometric Model for Pennsylvania

The Econometric Model will require an input-output table that describes not only the shipment of commodities among industries, but also their distribution throughout Pennsylvania and the rest of the world. For this purpose it will be necessary to identify shipments by commodity classification.

| FROM \ TO | AMOUNTS OF SHIPMENTS TO | | | | |
|---|---|---|---|---|---|
| | INDUSTRIES | | | GOVT | TOTALS |
| | I | II | III | | |
| Industry I (Tons) | 10 | 100 | 50 | 10 | 170 |
| Industry II (Cu.Ft.) | 20 | 4 | 46 | 10 | 80 |
| Industry III (Days) | 2 | 20 | 6 | 8 | 36 |

Table VII-1. Input-Output Flow of Goods and Services Among Industries

| FROM \ TO | COST OF SHIPMENTS TO | | | | |
|---|---|---|---|---|---|
| | INDUSTRIES | | | GOVT | TOTAL REVENUES |
| | I | II | III | | |
| Industry I | 10 | 100 | 50 | 10 | 170 |
| Industry II | 100 | 20 | 230 | 50 | 400 |
| Industry III | 20 | 200 | 60 | 80 | 360 |
| Total Costs | 130 | 320 | 340 | 140 | 930 |
| Differences | 40 | 80 | 20 | | |

Table VII-2. Input-Output Flows of Funds Arising from Interindustry Flow of Goods and Services

and by origin and destination. The table, then, will consist of a column and a row assigned to each industry at every node (important center of economic activity) in the State, and additional columns and rows for regions outside the State.

An important feature of the model will be the treatment of households as both consuming and producing industries. Households supply the labor and management needed by other industries. There will be a limit to this supply and this will be imposed by demographic constraints. For short run purposes it would be reasonable to expect little labor mobility, and the labor supply at each node would be the labor force already in that labor market. However, for long-run purposes it would be reasonable to expect considerable labor mobility, and the labor needed at any node could be drawn from a much larger area. The model is developed here assuming complete mobility within the State but assuming no change from the existing trends in migration. If, for any reason, it could prove desirable to extend or limit the type of mobility provided for, this can be done without altering the formal structure of the model.*

Households are, of course, consumers of the products of industry. In the usual input-output model such consumption is defined as "final demand" and is assumed to be determined outside the system. Changes in demand are generated by

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* By extending the study area for this model to regions adjacent to Pennsylvania, interstate migration patterns may be analyzed within the model.

exogenous forces such as growth in national income and in population. These changes in the demand become the driving force that leads the system to a new equilibrium. The proposed model will treat the consumption pattern at each node as given by some base year observation, but will allow the level of the demand at any given time to be determined by the population at that node at that time. Since labor mobility is allowed, the population will shift so as to conform with the labor requirements of the various industries at the several nodes.

The fundamental unit in the model will be the physical quantity of a commodity that is shipped from one place to another. This quantity is defined as follows. Let $X_{igjh}$ be the annual amount of commodity i produced in zone g that flows to industry j located in zone h. We assume that there is a one-to-one correspondence between commodity and industry. That is, commodity i is produced by industry i where i may symbolize agriculture, steel, glass, etc. If there are n industries, then i and j will have values 1,...,n. Similarly, if there are m nodes, g and h will have values 1,...,m. The amount $X_{igjh}$, for the most part, will be given in physical units, e.g. tons, but in certain cases will be expressed as dollar values.

For any given year (t) the complete set of all $X_{igjh}(t)$ for that year, written X(t), describes completely the flows of all commodities into and out of all nodes in the State. This set of $X_{igjh}(t)$ may be conveniently displayed in a table constructed in the manner shown in Table VII-3.

Although the physical quantities of the commodity flows are the prime interest of the transportation model, it is necessary for certain computational purposes to have these flows expressed in dollar terms. This may be done as follows: Let $p_{igjh}$ be the average price of $X_{igjh}$ at the point of origin, and let $f_{igjh}$ be the average cost of shipping $X_{igjh}$ from the point of origin to its destination. Then $Y_{igjh} = (p_{igjh} + f_{igjh}) X_{igjh}$ is the total delivered value of the amount of commodity i produced at node g and shipped to industry j at node h.* For any given year (t) the complete set of all $Y_{igjh}(t)$, written as Y(t), describes the money flows corresponding to the commodity flows into and out of all nodes in the State. A complete table Y(t) may be constructed in a form similar to that of the table X(t). Various totals and subtotals are defined as follows:

$$X_{igjo} = \sum_{h=1}^{m} X_{igjh}$$

= total shipments of industry i at g to industry j everywhere

$$X_{igoh} = \sum_{j=1}^{n} X_{igjh}$$

= total shipments of industry i at g to all industries at h

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* For purposes of the analysis it will be convenient to proceed as though all shipment costs pass through the books of the firm at the origin of the shipment and are included specifically as shipment costs in the price paid by the purchasing firm. These assumptions do not affect the equilibrium solutions of the model but simplify the analysis.

| From \ To | Industry 1 at Node | | Industry j at Node | Industry n at Node | | Total |
|---|---|---|---|---|---|---|
| | 1 .... m | | h | 1 .... m | | |
| Industry 1 at node 1 | | | | | | |
| 2 | | | | | | |
| . | | | | | | |
| . | | | | | | |
| . | | | | | | |
| m | | | | | | |
| S. Total | | | | | | |
| Industry 2 at node 1 | | | | | | |
| 2 | | | | | | |
| . | | | | | | |
| . | | | | | | |
| . | | | | | | |
| m | | | | | | |
| S. Total | | | | | | |
| Industry i at node g | | | $X_{igjh}$ | | | $X_{igoo}$ |
| Industry n at node 1 | | | | | | |
| 2 | | | | | | |
| . | | | | | | |
| . | | | | | | |
| . | | | | | | |
| m | | | | | | |
| S. Total | | | | | | |

Table VII-3. Interindustry Internodal Flows of Commodities and Services

$$X_{igoo} = \sum_{j=1}^{n} X_{igjo}$$

$$= \sum_{h=1}^{m} X_{igoh}$$

= total shipments of industry i at g

$$X_{iojh} = \sum_{g=1}^{m} X_{igjh}$$

= total shipments of commodity i received by industry j at h

$$X_{iooh} = \sum_{j=1}^{n} X_{iojh}$$

= total amount of commodity i shipped into node h

(VI

Totals of the Y's are defined in the same way as totals of the X's.

It should be noted that the $X_{igjh}$ cannot be summed over the values of the first subscript since this would involve the meaningless addition of different quantities of different commodities, e.g. tons of coal and yards of cloth. However, the Y's are all in dollar terms and summations of columns can be made. In particular $Y_{oojh} = \sum_{i=1}^{n} \sum_{g=1}^{m} Y_{igjh}$, the total expenditures of industry j at h for all purchases and for their shipment.

We now define ratios $R_{igjh}$ as follows:

$$R_{igjh} = Y_{igjh} \div Y_{oojh} \qquad \text{(VII-2)}$$

From this definition it follows that:

$$R_{igjh} \cdot Y_{oojh} = Y_{igjh} \qquad \text{(VII-3)}$$

Summing both sides of this relation over all values of j and h, we get:

$$\sum_{j=1}^{n} \sum_{h=1}^{m} R_{igjh} \cdot Y_{oojh} = \sum_{j=1}^{n} \sum_{h=1}^{m} Y_{igjh} = Y_{igoo} \qquad \text{(VII-4)}$$

The elements on both sides of equation (VII-4) will correspond to the entries in a given (i,g) row of the input-output table, and the total, $Y_{igoo}$, will be the gross revenue from sales.

We now suppose that the input-output table has been arranged so that the first m' modes are within Pennsylvania and the remaining m - m' nodes are outside the State. We may also suppose that the $n^{th}$ industry represents the government sector. Equation (VII-4) could now be modified as follows:

$$\sum_{j=1}^{n-1} \sum_{h=1}^{m'} R_{igjh} Y_{oojh} + \sum_{j=1}^{n-1} \sum_{h=m'+1}^{m} Y_{igjh} + \sum_{h=1}^{m} Y_{ignh} = Y_{igoo} \qquad \text{(VII-5)}$$

or

$$\sum_{j=1}^{n-1} \sum_{h=1}^{m'} R_{igjh} Y_{oojh} + E_{ig} + G_{ig} = Y_{igoo} \qquad \text{(VII-6)}$$

where $E_{ig}$ is the value of exports of industry i at node g, and $G_{ig}$ is the sum of all government purchases for that industry at that node.

Let the input-output tables be further expanded by the addition of a final row of differences of the kind described on p. 228 and illustrated in Table VII-2. Let the difference for the column (i,g) be designated $D_{ig}$. Then by definition:

$$D_{ig} = Y_{igoo} - Y_{ooig} \qquad \text{(VII-7)}$$

Equation (VII-6) may then be further modified:

$$\sum_{j=1}^{n-1} \sum_{h=1}^{m'} R_{igjh} Y_{oojh} + E_{ig} + G_{ih} - D_{ig} = Y_{ooig} \qquad \text{(VII-8)}$$

There will be an equation of this type for every industry represented by a row of data in the input-output table. These equations together form a system that may be conveniently represented in matrix notation as follows:

$$RY + E + G - D = Y \qquad \text{(VII-9)}$$

where $R = (R_{igjh})$ is a rectangular matrix formed by the technological coefficients included in equation (VII-8), $Y = (Y_{oojh})'$ is a column vector of total costs to the various industries, and $G = (G_{ig})$ and $D = (D_{ig})$ are also column vectors of the respective quantities defined above.

After rearranging the terms the matrix equation may be rewritten as:

$$(I-R)Y = E + G - D \qquad \text{(VII-10)}$$

This system will represent exactly the interregional interindustry flow of commodities and their corresponding money flows for any base period that may be selected and described

by the type of input-output table presented above. The actual values of the elements of the vector Y observed in the base year may also be looked upon as a particular solution for the system of equations represented by (VII-10), and for the particular values of the elements of the vectors E, G and D that obtained in that year. It is this latter view of the system that suggests its use as a forecasting device. If E, G and D are assumed to be determined outside the system and can be forecasted independently, and if the coefficients that compose R are assumed to be constant, then a new solution for the Y could be sought that satisfies (VII-10) with the forecasted values of E, G and D.

In order that practical use be made of the forecasting potential of equation (VII-10) it is necessary to examine the implications of the prerequisite that forecasts of E, G and D must be obtained. With this in mind, we shall examine these vectors separately.

First, with regard to E, exports from each node and industry may be given separately for different destinations and industries. However, it might be more realistic to collapse the export columns so as to represent different destinations but not different industries so that, for example, shipments of glass from Pittsburgh may be given for every node outside the State but not for any particular industry. In this case it would be necessary to forecast industry exports to each exterior node. This may be done by extrapolating trends that may be known or by adjusting base year levels to changes that may be expected to occur in

population and/or income in the respective nodes. For this purpose, the best available demographic and national income forecasts should be used. For nodes outside the U.S.A., it might be necessary to use level forecasts of no change from base year data, if no better information is available.

With regard to government purchases, it might be desirable to break these down into different parts. Much of government expenditures are of a kind that can be very accurately estimated in advance. This will be the case at every level of government. However, there are other government expenditures that are determined by changing policy considerations and by the exigencies of war and peace. With regard to these, little more than guesses may be possible.

The difference represented by an element of the vector D consists of the value added by the relevant industry. If we assume constant technology and no change in relative prices, then it would be reasonable to assume that the ratio of value added to total cost is constant. With this assumption it becomes possible to eliminate D as a vector to be forecasted.

This assumption would modify equation (VII-10) by deleting the vector D. One way to do this would be to treat the row of differences in the input-output table as if it were an industry. Then equation (VII-10) with the D vector eliminated will represent the complete system. The system of equations that will be used can be represented by a modified form of equation (VII-10) as follows:

$$Y - RY = E + G \qquad \text{(VII-10.1)}$$

## D. The Solution of the Input-Output System

The system represented by equation (VII-10.1) needs to be examined in some detail before we can set about describing the solution. Table VII-4 represents a way in which the commodity flows among industries and nodes inside and outside the State may be arranged. The table also represents a collapsing of columns that distinguish the industry destination of commodities exported from the State.

Suppose the data for the flows of commodities in Pennsylvania for some time period have been arranged according to the scheme of Table VII-4. We assume that the entries represent the money costs to the users of the goods and services involved. The elements in section (d) of the Totals column will be outputs of industries in Pennsylvania and correspond to the $Y_{igoo}$'s defined earlier. The elements in section (m) of the Totals row will be the $Y_{oojh}$, also defined earlier. When the "differences" given by section (i) are included in the totals of the columns as has been proposed, we get the relation:

$$Y_{igoo} = Y_{ooig} \qquad \text{(VII-11)}$$

Let the ratios $R_{igjh}$ defined at (VII-2) on p. 234 be computed for all the entries in sections (a), (e), and (i) of Table VII-4. We now form a set of matrices and vectors as follows:

R(a) = square matrix of all ratios computed for entries in section (a)

| From \ To | Industries at Nodes in State | Government at Nodes in State | Nodes Outside State | Totals |
|---|---|---|---|---|
| Industries at Nodes in State | In-State Interindustry Flows (a) | In-State Government Purchases (b) | Exports (c) | Y (d) |
| Industries at Nodes Outside State | Imports to Industries (e) | Imports to Government (f) | Through Traffic (g) | J (h) |
| Differences | D (i) | (j) | (k) | (l) |
| Totals | Y (m) | G (n) | E (o) | |

Table VII-4. System for Arranging Elements of Input-Output Table

R(e) = rectangular matrix of all ratios computed for entries in section (e)

R(i) = row vector of ratios computed for entries in section (i)

Y = column vector of Y's in section (d)

G(b) = column vector of totals of rows of elements in section (b)

G(f) = column vector of totals of rows of elements in section (f)

E = column vector of total of rows of elements in section (c)

J = totals of elements in sections (e) and (f) taken together

(VII-12)

With the above definitions a more precise representation of the input-output system may be presented as follows:

$$R(a) \cdot Y + G(b) + E = Y \qquad \text{(VII-13.1)}$$

$$R(e) \cdot Y + G(f) = J \qquad \text{(VII-13.2)}$$

Equation (VII-13.1) may be rewritten as

$$[I - R(a)]Y = G(b) + E \qquad \text{(VII-14)}$$

The solution to this system for any G(b) and E, and for a given R(a) would be

$$Y = [I - R(a)]^{-1} (G(b) + E) \qquad \text{(VII-15)}$$

Once Y has been determined then equation (VII-13.2) would be used to yield a solution for J for any G(f).

The solution of matrix equation (VII-15) would involve finding the inverse of the matrix [I - R(a)], and this is what would be done in the usual treatment of the input-output

model where there are assumed to be no limits to the productive capacity of the economy. However, this assumption is not realistic and it is proposed that such limits as exist should be imposed on the system. For example, at every node in the State the expansion of an industry may involve some (perhaps a proportionate) expansion of land use, but additional land may not be available for such use. This might be the case either because of geographic limitations or policy decisions.

Limits to the productive capacities of the industries at the various nodes should be written in the manner of the constraints in a linear programming mathematical model. Such constraints would have the form of the inequalities:

$$SY \leq C \qquad \text{(VII-16)}$$

C is a vector consisting of the maximum amounts of such limited resources as are available to the respective industries. S is a matrix of ratios that represent the amounts of the scarce resources needed to produce one dollar's output of the respective industries.

A constraint of particular interest was implied in an earlier discussion, in connection with the mobility of the population. In that discussion it was proposed that complete mobility of the labor force within Pennsylvania should be specified, but that there should be no more migration than what would be projected on the basis of latest trends. The effect of this proposal would be that it would be necessary to have a forecast of the total labor force available in

Pennsylvania for any given year before a solution could be obtained for the input-output model for that year.

Suppose that, for a specified year (t), the best available demographic forecast of the total Pennsylvania labor force was some number, say C(L,t). Then there would be a limit of C(L,t) to the number of laborers available to all industries in Pennsylvania. For every node in the State, the input-output table will have a row in which the entries represent the amounts of labor used by each industry at that node. These amounts may be in dollars or in hours. In such cases appropriate conversion factors must be developed, so that the amount of labor used in each node may be converted into the number of laborers employed. From this figure would be computed the ratio:

$$\text{(Number of Laborers)} \div \text{(Total Revenue)}$$

for each industry at each node. These ratios may then be arranged in proper sequence to compose a vector which we shall call S(L,t). The following inequality constraint will be imposed on the system:

$$S(L,t) \cdot Y \leq C(L,t) \qquad \text{(VII-17)}$$

One effect of imposing upon the system such constraints as (VII-17), or any others that may be represented by the inequalities at (VII-16), will be to make equation (VII-14) infeasible for certain values of G(b) and E. That is to say, if sufficient labor is not available it might not be possible for exports and government purchases to be as great as might

be predicted. This fact implies that equation (VII-14) should be converted to the inequality:

$$[I - R(a)]Y \leq G(b) + E \qquad \text{(VII-18)}$$

The foregoing discussion has led to the conclusion that the input-output system that represents the intercommodity flows in Pennsylvania is best represented by a set of inequalities, namely, those given at (VII-16), (VII-17) and (VII-18).

In general, there will be an infinite number of solutions to this set of inequalities. In particular, $Y = 0$ is a feasible solution. That is, all of the inequalities will be satisfied if nothing is produced in all of Pennsylvania. It is obvious that such a solution could not be a rational forecast for the State for any year. Fortunately, there are a number of ways in which more or less satisfactory solutions to the system can be found. These involve the definition of some objective function to be maximized, or minimized.

In economic theory the principle of profit maximization has been used as the most reasonable assumption for purposes of analyzing the behavior of the firm. A method of adapting this principle to our model would involve the feasibility of the maximization of the sum of the differences given in row (i) of Table VII-4. However, we have already shown that this sum must be identically zero. The difficulty might be overcome by deleting certain elements of D that would be negative because of the way in which Table VII-4 is constructed. For example, the household sectors would tend to show greater expenditures than receipts if the table excluded purely

financial transactions. This would mean that at least some elements of D corresponding to the household sectors at each node would be negative. If the household sector is deleted from the vector D, then the sum of the remaining elements would be positive and would increase with increasing output. There might have to be some arbitrariness in the selection of the sectors to be deleted, but it would not be unreasonable to use the sum of the remaining elements as the function to be maximized. That would mean that the objective function becomes:

$$Z_1 = \overset{o}{R}(i)Y \qquad \text{(VII-19)}$$

where $\overset{o}{R}(i)$ is the same as R(i) except that certain ratios have been replaced by zeros.

A public policy aimed at maximizing the economic growth of Pennsylvania might suggest that the sum of the elements in the Y vector should be maximized. That is, the total revenue from sales of products included in the model should be as large as possible. This would define $Z_2$ as the objective function, where:

$$Z_2 = uY \qquad \text{(VII-20)}$$

and where u is the unit vector compatible with Y.

An alternative public policy might be to minimize unemployment in the State. This might be made the basis of an objective function that would drive the system to a viable solution. From the definition of the terms in the inequality

at (VII-17), it follows that the level of unemployment is given by:

$$Z_3 = C(L,t) - S(L,t) \cdot Y \qquad \text{(VII-21)}$$

It is clear from (VII-21) that minimizing $Z_3$ is equivalent to maximizing employment. Thus the objective function to be maximized would be:

$$Z_4 = S(L,t) \cdot Y \qquad \text{(VII-22)}$$

The functions suggested for maximization have been justified on the basis of some "reasonable" policy. However, if the elements of (G(b) + E), on the right hand side of the inequality (VII-18), should be attainable within the other constraints imposed on the system, it would be the case that the solutions obtained by maximizing all of a large class of objective functions would be identical. That is, any one of such objective functions would drive the system to the same solution. In general, this solution would involve having none of the limited resources used to full capacity.

If, on the other hand, all of (G(b) + E) is not attainable within the other constraints, it is not obvious that all such objective functions would lead to the same solution. It is, therefore, of some concern which objective function should be chosen. It is recommended that, before a decision is made, some experimentation should be undertaken with pilot studies of available data to compare the solutions obtained by the use of different objective functions of the type suggested above.

It should be emphasized that the use of an objective function is intended as a mathematical device for driving the linear programming algorithm to a solution that is consistent with the description of the Pennsylvania economy implied by the input-output model. There is no intention of defining what should be an objective of public policy. For this reason, the minimization of unemployment might be a least offensive objective, especially if the constraint inequality at (VII-17) should be modified to reflect some "reasonable" level of unemployment.

When a solution to the system is obtained the total output of each industry is forecasted, together with the levels of imports, exports, and of government expenditures. If the elements of the forecasted Y vector are multiplied by the corresponding elements of the matrices R(a) and R(e), forecasts will be generated for all of the respective inter-industry flows of commodities in sections (a) and (e) of Table VII-4. These forecasts will be in money terms. In order that they may be used to describe expected physical flows, it will be necessary to develop conversion factors that represent the dollar value (or price) per physical unit of each of the commodities involved at each of the originating nodes.

In the following section, an analysis is undertaken to show that the elements of R depend on prices and on costs of transportation. The analysis then shows how forecasted changes in such prices and costs of transportation may be incorporated into the model to create a measure of the impact

of transportation changes on the economy of Pennsylvania. The prices discussed in the following section will be the conversion factors needed for the purpose presented in the previous paragraph.

## E. Theoretical Framework of the Econometric Model

In the usual Leontief input-output model, the ratios

$$R_{igjh} = Y_{igjh}/Y_{oojh}$$

are formed.* Each ratio $R_{igjh}$, so defined, is called a technological coefficient and is the proportion of total expenditure of firm j at node h that goes to purchase commodity i at node g. If these technological coefficients are assumed to be constant, the input-output model becomes consistent with the assumption that all industries have constant returns to scale. In addition, there is the implication that total expenditures for any commodity are insensitive to price changes. This, in turn, implies that industries operate like firms which minimize costs (or maximize profits) and have a very special form of linear homogeneous production function, the Cobb-Douglas production function, which may

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* The model usually omits specification of the originating node g on the assumption that commodity i from all nodes is identical. The ratios then become $Y_{ijk}/Y_{ojk}$. The model here presented does not make the above assumption for two main reasons. The first is that, with the aggregation involved in any feasible commodity classification, there will be considerable variation in the composition of shipments of the same class from firms at different nodes. The second reason for the specification of the point of origin is that this permits the development of a transportation sensitivity not possible without it.

be represented by the equation:

$$X_{jhoo} = \prod_{i=1}^{n} \prod_{g=1}^{m} X_{igjh}^{\alpha_{igjh}} \qquad \text{(VII-23)}$$

where the assumption is made that:

$$\sum_{j=1}^{n} \sum_{h=1}^{m} \alpha_{igjh} = 1 \qquad \text{(VII-24)}$$

The following simple example of a firm producing one output and using two inputs will illustrate the foregoing statements. Suppose the firm's production function is given by:

$$Z = 5X_1^{1/3} X_2^{2/3} \qquad \text{(VII-25)}$$

Suppose $p_1$ = the price of the first input and

$p_2$ = the price of the second input;

then the cost of any level of output is:

$$C = p_1 X_1 + p_2 X_2 \qquad \text{(VII-26)}$$

The problem is to minimize C subject to $Z = 5X_1^{1/3} X_2^{2/3}$ for any given Z. We use the usual Lagrangian procedure for obtaining an extremum:

$$L = p_1X_1 + p_2X_2 + \lambda(Z - 5X_1^{1/3} X_2^{2/3})$$

Then the partial derivatives are set equal to zero as follows:

$$\frac{\partial L}{\partial X_1} = p_1 - \lambda(\frac{5}{3} X_1^{-2/3} X_2^{2/3}) = 0$$

$$\frac{\partial L}{\partial X_2} = p_2 - \lambda(\frac{10}{3} X_1^{1/3} X_2^{-1/3}) = 0$$

$$\therefore \quad p_1 = \frac{5}{3} \lambda X_1^{-2/3} X_2^{2/3}$$

$$\text{and} \quad p_2 = \frac{10}{3} \lambda X_1^{1/3} X_2^{-1/3}$$

Taking the ratios of both sides of these equations and simplifying we get

$$\frac{p_1}{p_2} = 1/2 \frac{X_2}{X_1} \quad \text{and}$$

$$p_1 X_1 = 1/2 \; p_2 X_2 \tag{VII-27}$$

This relationship between expenditures on the two inputs is constant regardless of the level of output or any changes that may take place in input prices.

Now, for any level of output, $C = p_1X_1 + p_2X_2$. Substituting from (VII-27) we get minimum cost $= 1/2(p_2X_2) + p_2X_2$. That is, at optimum

$$C = 3/2(p_2X_2)$$

$$\therefore \; p_2X_2 = 2/3 \; C \tag{VII-28}$$

$$X_2 = 2/3 \; C/p_2$$

similarly,

$$p_1X_1 = 1/3 \; C$$

hence

$$X_1 = 1/3 \; C/p_1 \tag{VII-29}$$

and

$$\frac{X_1}{X_2} = \frac{p_2}{2p_1} \tag{VII-30}$$

and $$X_1 = p_2X_2/2p_1 \ *$$ (VII-31)

But in (VII-25) we have:

$$Z = 5X_1^{1/3} X_2^{2/3}$$

Substituting for $X_1$ using relationship (VII-31) we get:

$$Z = 5[1/2(p_2/p_1)X_2]^{1/3} X_2^{2/3}$$

$$Z = 5(p_2/2p_1)^{1/3} X_2 = 5(2p_1/p_2)^{2/3} X_1 \quad \text{(VII-32)}$$

by equation (VII-30). Thus, for minimum cost of any level of production, output is a linear homogeneous function of any of the inputs. Figure VII-1 illustrates the solution.

The curve Z represents the various combinations of $X_1$ and $X_2$ that yield the output Z according to the given production function. The curve Z' represents a level of output higher than Z. The line joining $C/p_1$ and $C/p_2$ represents the combinations of $X_1$ and $X_2$ that can be purchased with a given budget C when prices are $p_1$ and $p_2$ respectively. The point B shows the optimum combination of $X_1$ and $X_2$ for a given budget C and indicates that Z is the highest level of output obtainable with this budget.

The ray OA is an expansion path. It gives the optimum combinations of $X_1$ and $X_2$ in the fixed proportion, $X_1/X_2 = p_2/2p_1$, that would be used for all levels of output with

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* It can be shown that the solution obtained is, indeed, a minimum. That is, the second order conditions for a minimum are satisfied.

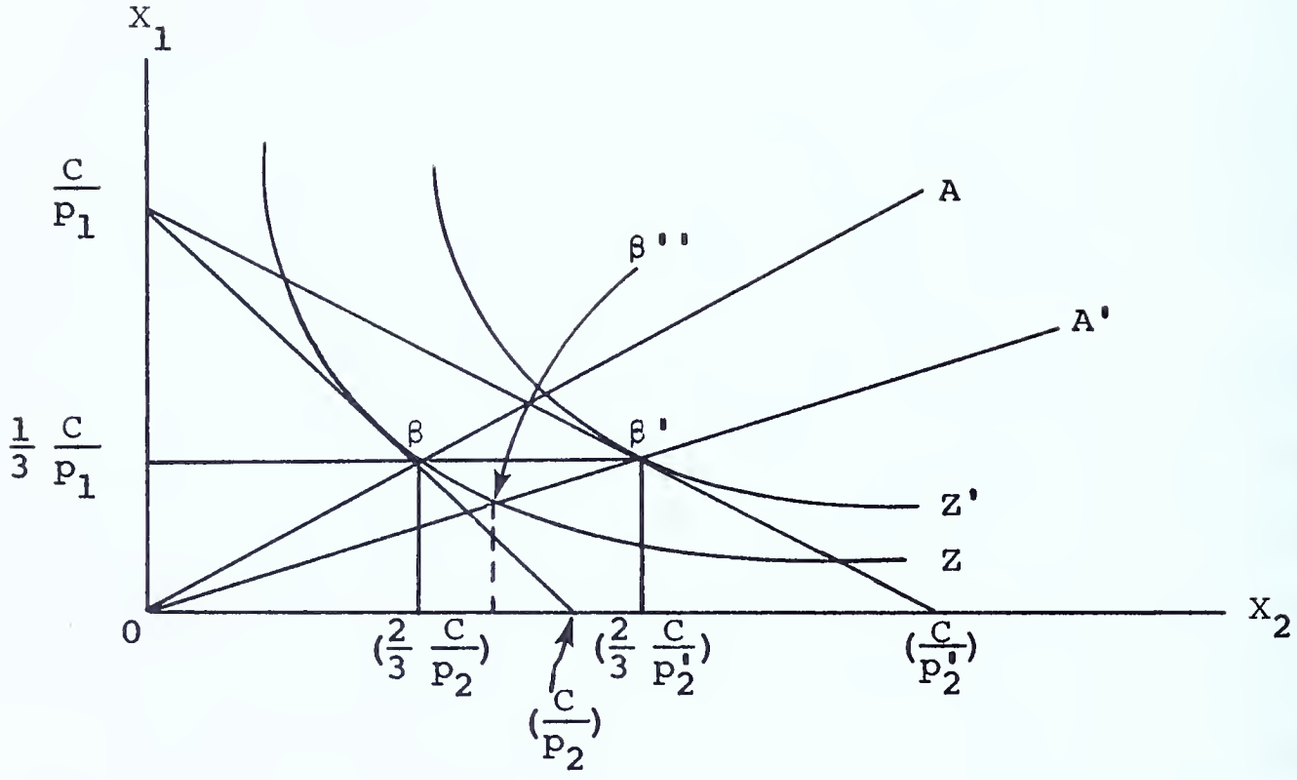


Figure VII-1. Determination of Optimum Input Combinations

the prices held constant. If the price $p_2$ should fall to $p_2'$ then the expansion path becomes OA'. Note that the fall in price $p_2$ to $p_2'$ leads to no change in the quantity $X_1$ if total expenditures for all resources ($X_1$ and $X_2$) remain fixed at C. It does, however, lead to an increase in the quantity of $X_2$ from $2/3(C/p_2)$ to $2/3(C/p_2')$, and to an increase in the physical volume of output from Z to Z'.

If, however, the output needed does not rise to Z' then the quantity Z would be most efficiently produced with the combinations of $X_1$ and $X_2$ at the point B" where the curve Z cuts the expansion path A'. At this point the ratio of the costs of the inputs remains as it was before, but the actual costs of both inputs are cut by the same proportion. Thus, at whatever level of output the firm operates, the ratio of expenditures on the inputs is constant for efficient production. It was shown at (VII-28) and (VII-29) above that actual expenditures were as follows:

$$p_1X_1 = 1/3\ C$$

$$p_2X_2 = 2/3\ C$$

That is, 1/3 of the budget was spent for $X_1$ and 2/3 was spent for $X_2$. It will be noted that these ratios are exponents of the respective X's in the production function and, therefore, that the production function can be derived from observation of actual expenditures for the different inputs in the following manner. Let

$$Z = \beta X_1^{\alpha_1} X_2^{\alpha_2} \qquad \text{(VII-33)}$$

If the expenditures $p_1X_1$ and $p_2X_2$ are observed then the estimates of the $\alpha$'s would be

$$\hat{\alpha}_1 = p_1X_1 \div C$$
$$\hat{\alpha}_2 = p_2X_2 \div C \qquad \text{(VII-34)}$$

where

$$C = p_1X_1 + p_2X_2$$
$$\hat{\beta} = Z \div X_1^{\hat{\alpha}_1} X_2^{\hat{\alpha}_2} \qquad \text{(VII-35)}$$

In order to estimate $\beta$ the physical quantities of inputs and outputs are needed. When the $\alpha$'s have been estimated it becomes possible to estimate the changes in the proportions of the physical quantities of the inputs that result from a change in any of their prices.

The foregoing results that have been obtained for the simple case of two inputs can be generalized readily for any number of inputs. This implies that if a production function of the Cobb-Douglas type is assumed to be the theoretical framework of a Leontief input-output model of interregional interindustry flows of commodities, then the model can be used to show how changes in the prices of commodities will effect changes in the physical flows while maintaining the constant proportions of money flows assumed in the model. Since the price of commodities to the user includes the cost of transportation then changes in the cost of transportation also can be analyzed by the model.

From the above analysis, it is apparent that the $\alpha$'s of the respective production functions will be equal to the

corresponding technological coefficients, the R's, of the input-output model if the system is at equilibrium. This means that, if the assumption of equilibrium is made, then the $\alpha$'s and $\beta$'s for the production functions of each industry may be estimated from the observed money flows. The generalization of (VII-34) is that the estimate of $\hat{\alpha}_{igjh}$ would be $R_{igjh}$ defined at (VII-2).

Once the production functions are known, the expansion paths corresponding to any set of prices may be computed. The new expansion paths can then be used to determine the equilibrium solution of input-output flows for any given vector of final demands. The method by which this may be done is given in Appendix VII-A.

## F. A Modification of the Model

It has been stated already that the input-output model assumes constant technological coefficients, that is, fixed proportions in the ratios of dollar expenditures for the different inputs of each industry. In the previous analysis it was shown how an underlying production function can be estimated and used to forecast changes in the proportions of physical quantities of inputs, and hence freight movement, that would result from changes in prices and changes in the cost of transportation. The price sensitivity introduced by this means might be adequate for practical purposes when inputs are aggregated and classified so that no commodity class is a good substitute for another. However, inter-industry interregional commodity movements typically show

commodities of the same class, but from different regions, as inputs of the same industry. For instance, the construction industry at Harrisburg will use steel from Pittsburgh, from Bethlehem, and from other areas as well. In such cases, it seems reasonable to suppose that a change in the price differentials among such competing sources of the same commodity class will result in more or less considerable change in the money flows as well as in the physical movement of these commodities. Thus, to continue the above example, an improvement in transportation that would reduce significantly the delivered price of Pittsburgh steel in Harrisburg should be expected to lead to shifts in expenditures away from competing sources and towards the Pittsburgh source. The input-output models so far developed have not been able to forecast such shifts. The following modification is sufficiently flexible to do this.

The variables in the model are defined as before. The proposed production function is given by the formula:

$$X_{jhoo} = \Theta_{jh} \prod_{i=1}^{n} \left[ \sum_{g=1}^{m} (\alpha_{igjh} X_{igjh})^{\beta_{ijh}} \right]^{\frac{\gamma_{ijh}}{\beta_{ijh}}} \qquad \text{(VII-36)}$$

This formula is a combination of the Cobb-Douglas function given above and a "constant elasticity of substitution" production function. The Cobb-Douglas part of the function is seen in the following collapsed form:

$$X_{jhoo} = \Theta_{jh} \prod_{i=1}^{n} X_i^{\gamma_{ijh}} \qquad \text{(VII-37)}$$

where

$$X_i = \left[ \sum_{g=1}^{m} (\alpha_{igjh} X_{igjh})^{\beta_{ijh}} \right]^{1/\beta_{ijh}} \qquad \text{(VII-38)}$$

The Cobb-Douglas feature of the function affords the limited price and transportation sensitivity formally discussed in connection with that function. But this limitation is confined to only the relationships among the different classes of commodities. A considerably greater degree of price and transportation sensitivity is possible among the different sources within any given class of commodities. This additional sensitivity is derived from the constant elasticity of substitution feature of the function, which is that part given by equation (VII-38).

The total effect of the function given is to provide that any given industry will maintain the same ratios for expenditures among commodities of different classes, but may vary the shares of the expenditures, on any given class, that go to different sources. In our example, it would be assumed that the construction industry in Harrisburg will purchase, for example, steel and cement in fixed proportions (in dollar terms) but may shift its steel purchases from Bethlehem to Pittsburgh if price differentials move in favor of Pittsburgh. The precise nature of the shifts will become apparent from the following analysis.

It may be shown that the proposed function is linear and homogeneous, and therefore satisfies the basic assumption of the Leontief input-output model. Let

$$X = \Theta \prod_{i=1}^{n} \left[ \sum_{g=1}^{m} (\alpha_{ig} X_{ig})^{\beta_i} \right]^{\gamma_i/\beta_i} \qquad \text{(VII-39)}$$

where the subscripts j and h have been dropped for simplicity. If the partial derivative of X with respect to $X_{IG}$, for any I and G, is multiplied by $X_{IG}$ we get:

$$X_{IG} \cdot \frac{\partial X}{\partial X_{IG}} = \frac{\gamma_I \Theta \prod_{i=1}^{n} \left[ \sum_{g=1}^{m} (\alpha_{ig} X_{ig})^{\beta_i} \right]^{\gamma_i/\beta_i} (\alpha_{IG} X_{IG})^{\beta_I}}{\sum_{g=1}^{m} (\alpha_{Ig} X_{Ig})^{\beta_I}}$$

$$= \frac{\gamma_I (\alpha_{IG} X_{IG})^{\beta_i}}{\sum_{g=1}^{m} (\alpha_{Ig} X_{Ig})^{\beta_I}} X$$

These products are summed over all possible G's and I's to yield:

$$\sum_{I=1}^{n} \sum_{G=1}^{m} \frac{\partial X}{\partial X_{IG}} X_{IG} = \sum_{I=1}^{n} \gamma_I X \qquad \text{(VII-40)}$$

By Euler's theorem, the above result shows that the function at (VII-39) is homogeneous of a degree equal to $\sum_{I=1}^{n} \gamma_I$. It follows that the necessary and sufficient condition for X to be a linear and homogeneous function is that the sum of the $\gamma_I$ be equal to one.

We now assume, as before, that each industry behaves as a single firm in combining its inputs so as to produce any level of output at minimum cost. We wish to minimize

$$C = \sum_{i=1}^{n} \sum_{g=1}^{m} p_{ig} X_{ig} \qquad \text{(VII-41)}$$

given that

$$X = \Theta \prod_{i=1}^{n} \left[ \sum_{g=1}^{m} (\alpha_{ig} X_{ig})^{\beta_i} \right]^{\gamma_i/\beta_i} \qquad \text{(VII-42)}$$

for any X, where again the subscripts j and h that identify the relevant industry and location have been dropped for simplicity.

We define the Lagrangian function:

$$L = \sum_{i=1}^{n} \sum_{g=1}^{m} p_{ig} X_{ig} + \lambda \left\{ X - \Theta \prod_{i=1}^{n} \left[ \sum_{g=1}^{m} (\alpha_{ig} X_{ig})^{\beta_i} \right]^{\gamma_i/\beta_i} \right\} \qquad \text{(VII-43)}$$

We set the partial derivatives equal to zero and obtain:

$$\frac{\partial L}{\partial X_{IG}} = p_{IG} - \frac{\lambda \left\{ \gamma_I \alpha_{IG}^{\beta_I} X_{IG}^{\beta_I - 1} \Theta \prod_{i=1}^{n} \left[ \sum_{g=1}^{m} (\alpha_{ig} X_{ig})^{\beta_i} \right]^{\gamma_i/\beta_i} \right\}}{\sum_{g=1}^{m} (\alpha_{Ig} X_{Ig})^{\beta_I}}$$

$$= 0$$

for all I = 1,...,n; G = 1,...,m. Multiplying through by $X_{IG}$ and using (VII-42) we get:

$$p_{IG} X_{IG} = \lambda \gamma_I (\alpha_{IG} X_{IG})^{\beta_I} X \div \sum_{g=1}^{m} (\alpha_{Ig} X_{ig})^{\beta_i} \qquad \text{(VII-44)}$$

Summing both sides of this expression for all G's we get:

$$\sum_{g=1}^{m} p_{Ig} X_{Ig} = \lambda \gamma_I X$$

Therefore

$$\gamma_I = \sum_{g=1}^{m} p_{Ig} X_{Ig} \div \lambda X \qquad \text{(VII-45)}$$

for any I. Again, summing over all possible values of I,

$$\sum_{i=1}^{n} \gamma_i = \sum_{i=1}^{n} \sum_{g=1}^{m} (p_{ig} X_{ig}) \div \lambda X \qquad \text{(VII-46)}$$

but, from assumption of linear homogeneity:

$$\sum_{i=1}^{n} \gamma_i = 1$$

Therefore, from (VII-46):

$$\sum_{i=1}^{n} \sum_{g=1}^{m} p_{ig} X_{ig} = \lambda X \qquad \text{(VII-47)}$$

But X is the physical volume of output, and the left hand side of (VII-47) is the total cost of production. It follows that:

$$\lambda = \frac{\text{Total Cost}}{\text{Output}} = \text{Average cost of the output}$$

Substituting the result of (VII-47) into (VII-45) we have

$$\gamma_i = \sum_{g=1}^{m} p_{ig} X_{ig} \div \sum_{i=1}^{n} \sum_{g=1}^{m} p_{ig} X_{ig} = \frac{C_i}{C} \qquad \text{(VII-48)}$$

where the C's are so defined. That is, for optimum use of resources, the industry's expenditures on commodity i will be the constant ratio $\gamma_i$ of its total expenditures.

We already have from (VII-44) that, for any i and g:

$$p_{ig} = \lambda \gamma_i \alpha_{ig}^{\beta_i} X_{ig}^{\beta_i - 1} X \div \sum_{g=1}^{m} (\alpha_{ig} X_{ig})^{\beta_i} \qquad \text{(VII-49)}$$

For any commodity i from any two sources G and H, we may write two equations of the form of (VII-49) by writing the expression for $p_{iG}$ and for $p_{iH}$ respectively. Ratios formed from these two equations yield:

$$\frac{p_{iG}}{p_{iH}} = \frac{\alpha_{iG}^{\beta_i} X_{iG}^{\beta_i - 1}}{\alpha_{iH}^{\beta_i} X_{iH}^{\beta_i - 1}} \qquad \text{(VII-50)}$$

Rearranging terms, we have:

$$\left(\frac{X_{iG}}{X_{iH}}\right)^{\beta_i - 1} = \left(\frac{\alpha_{iH}}{\alpha_{iG}}\right)^{\beta_i} \frac{p_{iG}}{p_{iH}} \qquad \text{(VII-51)}$$

Taking the $(\beta_i - 1)$ root:

$$\frac{X_{iG}}{X_{iH}} = \left(\frac{\alpha_{iH}}{\alpha_{iG}}\right)^{\beta_i/\beta_i - 1} \left(\frac{p_{iG}}{p_{iH}}\right)^{1/\beta_i - 1} \qquad \text{(VII-52)}$$

Multiplying both sides by $X_{iH}\, p_{iG}$ and summing over the G yields:

$$\sum_{g=1}^{m} X_{ig}\, p_{ig} = X_{iH}\, p_{iH}^{1/1-\beta_i}\, \alpha_{iH}^{\beta_i/1-\beta_i} \sum_{g=1}^{m} \left(\frac{\alpha_{ig}}{p_{ig}}\right)^{\beta_i/1-\beta_i} \qquad \text{(VII-53)}$$

Hence, by rearranging terms, we have:

$$X_{iH} = \frac{C_i}{p_{iH}} \div \sum_{g=1}^{m} \left(\frac{\alpha_{ig}}{\alpha_{iH}} \frac{p_{iH}}{p_{ig}}\right)^{\beta_i/1-\beta_i} \qquad \text{(VII-54)}$$

where by definition $C_i = \sum_{G=1}^{m} p_{iG}\, X_{iG}$.

This expression represents the optimum quantity of the commodity i that the firm will purchase from the $H^{th}$ source if it wishes to minimize its production costs. This optimum

quantity depends not only on the price at the $H^{th}$ source, but also on the ratios of that price with each of the prices at the other sources. The expression, therefore, represents an optimum demand function in the sense that it states what the purchase should be at any set of prices that may obtain.

An analysis of the elasticity of substitution, which follows, shows that the $\beta_i$ must be positive but less than unity. This implies, from inspection of the above demand function, that $X_{iH}$ will be zero if the corresponding $\alpha_{iH}$ is zero.

The elasticity of substitution of any two inputs to a production process is defined as the proportionate change in the ratio of the amounts of the inputs divided by the proportionate change in their marginal physical productivities. The mathematically equivalent formula is given by:

$$E_{GH} = \frac{\partial X}{\partial X_{iG}} \cdot \frac{\partial X}{\partial X_{iH}} \div X \cdot \frac{\partial^2 X}{\partial X_{iG}\, \partial X_{iH}} \qquad \text{(VII-55)}$$

In the case of our production function, it may be shown that:

$$E_{GH} = \frac{1}{1 - \beta_i/\gamma_i} \qquad \text{(VII-56)}$$

This elasticity should be greater than unity in order that the price sensitivity required by the model be realized. That is, we expect that

$$\frac{1}{1 - \beta_i/\gamma_i} > 1 \qquad \text{(VII-57)}$$

which will be the case if $0 < \frac{\beta_i}{\gamma_i} < 1$. We have already shown that linear homogeneity requires that:

$$\sum_{i=1}^{n} \gamma_i = 1$$

It may also be shown that each $\gamma_i$ must be non-negative in order that the production function behave so as to give the second order conditions for cost minimization. These considerations, taken together, yield the result that:

$$0 < \beta_i < \gamma_i < 1 \qquad \text{(VII-58)}$$

that is, that $\beta_i$ is some positive fraction less than unity. The foregoing results show how industry's expenditures will be distributed under the cost minimizing assumption.*

If the $\beta$'s and $\alpha$'s are known, it would be possible to estimate from the foregoing results the volumes of purchases by any industry of all commodities from all sources. It would be necessary, however, to know the prices, since these enter into the optimum distribution of the industry's expenditures.

The following procedure shows how estimates for the $\alpha$'s and $\beta$'s may be obtained from the data in the input-output table. At (VII-50) we have:

$$\frac{p_{iG}}{p_{iH}} = \frac{\alpha_{iG}^{\beta_i} X_{iG}^{\beta_i - 1}}{\alpha_{iH}^{\beta_i} X_{iH}^{\beta_i - 1}}$$

---

* Note - It can be shown that the second order conditions for a minimum hold for positive values of the $\alpha$'s, and for not very restrictive conditions on the $\beta$'s and $\gamma$'s.

Multiplying by $\frac{X_{iG}}{X_{iH}}$ yields:

$$\frac{p_{iG}\, X_{iG}}{p_{iH}\, X_{iH}} = \left(\frac{\alpha_{iG}}{\alpha_{iH}}\right)^{\beta_i} \left(\frac{X_{iG}}{X_{iH}}\right)^{\beta_i} \qquad \text{(VII-59)}$$

Taking the logarithms we have:

$$\log \frac{p_{iG}\, X_{iG}}{p_{iH}\, X_{iH}} = \beta_i \left(\log \frac{\alpha_{iG}}{\alpha_{iH}} + \log \frac{X_{iG}}{X_{iH}}\right) \qquad \text{(VII-60)}$$

Therefore

$$\log \frac{X_{iG}}{X_{iH}} = - \log \frac{\alpha_{iG}}{\alpha_{iH}} + \frac{1}{\beta_i} \log \frac{p_{iG}\, X_{iG}}{p_{iH}\, X_{iH}} \qquad \text{(VII-61)}$$

For any industry i there will be m' non-zero $\alpha$'s and hence m' observations possible on the corresponding X's and p's. Let $\alpha_{iH}$ represent any one, say, the first, of the non-zero $\alpha$'s. There will be (m' - 1) ratios of the kind in equation (VII-61) above and hence (m' - 1) of these equations may be constructed. These (m' - 1) equations will contain (m' - 1) ratios of the $\alpha$'s, such as $\frac{\alpha_{iG}}{\alpha_{iH}}$, and the ratio $\frac{1}{\beta_i}$. It follows that a unique solution for these ratios does not exist unless some further restriction is imposed. The following is suggested if estimates must be made on the basis of data in a single input-output table:*

$$\sum_{G=2}^{m'} \log \frac{\alpha_{iG}}{\alpha_{il}} = 0 \qquad \text{(VII-62)}$$

---

* Note that equation (VII-62) would result from a stepwise least-squares procedure that first estimates $1/\beta_i$ by minimizing the sum of the squares of $-\log (\alpha_{ig}/\alpha_{ih})$.

The m' observations may be used now to obtain values for the ratios $\frac{\alpha_{iG}}{\alpha_{il}}$ and the $\beta_i$. Since there are m' parameters to be estimated from m' observations, the estimates will give an exact fit to the data.* If the survey (or sample) data for individual firms is available, it becomes possible to estimate the above ratios by usual statistical techniques for cross-sectional data without imposing the restriction (VII-62). The procedure for estimating the $\beta$'s and the ratios of the $\alpha$'s is described in the following section.

## G. Estimation Procedure

The equation (VII-61) may be written in the following simplified form

$$Y_G = -A_G + bW_G \quad (G=2,\ldots,m') \qquad \text{(VII-63)}$$

where we define the terms of equation (VII-63) as follows:

$$\begin{aligned} Y_G &= \log \frac{X_{iG}}{X_{iH}} \\ A_G &= \log \frac{\alpha_{iG}}{\alpha_{iH}} \\ b &= \frac{1}{\beta_i} \\ W_G &= \log \frac{p_{iG}\, X_{iG}}{p_{iH}\, X_{iH}} \end{aligned} \qquad \text{(VII-64)}$$

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* With regard to the nature of the estimates that will be obtained by the exact fit of the data, it should be remembered that the functions being estimated are descriptive of the aggregate behavior of as many firms in the region as there are in the aggregate of industries defined by the commodity classification used. There should, therefore, be more stability in the aggregate than there would be in the behavior of individual firms.

Equation (VII-61) holds for any G and H within any industry i. Hence we may select arbitrarily H as the first source, in some original ordering of sources, from which the producing industry under consideration purchases some of commodity i. The corresponding $\alpha_{iH}$ is, therefore, the first non-zero $\alpha$ in that listing. All the non-zero $\alpha$'s may now be renumbered so that $\alpha_{iH}$ becomes $\alpha_{i1}$ and the last becomes $\alpha_{im'}$. The definitions at (VII-64) above are for all $g = 2,\ldots,m'$ as there indicated.

The normalizing assumption (VII-62) may be written as:

$$\sum_{g=2}^{m'} A_g = 0 \qquad \text{(VII-65)}$$

Summing both sides of equation (VII-63) we get:

$$\sum_{g=2}^{m'} Y_g = -\sum_{g=2}^{m'} A_g + b \sum_{g=2}^{m'} W_g \qquad \text{(VII-66)}$$

$$= b \sum_{g=2}^{m'} W_g \quad \ldots \quad \text{by (VII-65).}$$

Therefore

$$b = \sum_{g=2}^{m'} Y_g \div \sum_{g=2}^{m'} W_g \qquad \text{(VII-67)}$$

Substituting (VII-67) into (VII-63), we get:

$$Y_G = -A_G + W_G \frac{\sum_{g=2}^{m'} Y_g}{\sum_{g=2}^{m'} W_g} \qquad \text{(VII-68)}$$

Therefore

$$A_G = W_G \frac{\sum_{g=2}^{m'} Y_g}{\sum_{g=2}^{m'} W_g} - Y_G \qquad \text{(VII-69)}$$

From (VII-67) and (VII-69), and from the definitions at (VII-64), it is apparent that estimates may be derived for $\beta_i$ and for all the ratios $\frac{\alpha_{ig}}{\alpha_{il}}$, for g = 2,...,m'. It is necessary to demonstrate that these estimates are sufficient to derive the distribution of the industry's expenditures on commodity i among all of its sources.

By multiplying both sides of equation (VII-54) by $p_{iH}/C_i$ and by defining $r_{iH}$ appropriately, we get:

$$r_{iH} = \frac{X_{iH}\, p_{iH}}{C_i} = \frac{1}{\sum_{g=1}^{m} \left( \frac{\alpha_{ig}}{\alpha_{iH}} \frac{p_{iH}}{p_{ig}} \right)^{\beta_i/1-\beta_i}} \qquad \text{(VII-70)}$$

where $r_{iH}$ so defined is the proportion of the expenditure $C_i$ that goes to the source H.

Since in (VII-70) and $\alpha$'s appear only as ratios of pairs, it follows that if all the ratios $\frac{\alpha_{ig}}{\alpha_{il}}$, g=2,...,m', are known then all other ratios of pairs may be computed by the formula:

$$\frac{\alpha_{ig}}{\alpha_{iH}} = \frac{\alpha_{ig}}{\alpha_{il}} \div \frac{\alpha_{iH}}{\alpha_{il}} \qquad \text{(VII-71)}$$

Since all ratios of the $\alpha$'s and the $\beta$'s may be estimated as shown above, it follows that all that is needed to compute $r_{iH}$ is the set of prices from all the competing sources, that is, the set of prices $p_{il},\ldots,p_{im'}$. It is apparent from equation (VII-70) that $r_{iH}$ is a nonlinear function of the ratio of the price $p_{iH}$ to each of the other prices. It will be of considerable importance for the transportation model how this ratio changes in response to changes in these prices.

We define $E(r_{iH};\ p_{iG})$ as the elasticity of $r_{iH}$ with respect to the price $p_{iG}$. Following the usual economic definition of elasticity as the proportionate change in $r_{iH}$ due to a small proportionate change in $p_{iG}$, we may compute $E(r_{iH};\ p_{iG})$ by means of the formula (VII-72):

$$E(r_{iH};\ p_{iG}) = \frac{\partial r_{iH}}{\partial p_{iG}} \cdot \frac{p_{iG}}{r_{iH}} \qquad \text{(VII-72)}$$

It may be shown that:

$$E(r_{iH};\ p_{iG}) = \frac{\beta_i}{1-\beta_i} \left( \frac{\alpha_{iG}}{\alpha_{iH}} \frac{p_{iH}}{p_{iG}} \right)^{\beta_i/1-\beta_i} r_{iH} \quad (G \neq H) \qquad \text{(VII-73)}$$

$$E(r_{iH};\ p_{iH}) = -\frac{\beta_i}{1-\beta_i} \sum_{g \neq H} \left( \frac{\alpha_{ig}}{\alpha_{iH}} \frac{p_{iH}}{p_{ig}} \right)^{\beta_i/1-\beta_i} r_{iH} \quad (G=H) \qquad \text{(VII-74)}$$

The foregoing elasticities are of fundamental importance to the transportation model. They provide a formula for changing the technological coefficients of the input-output model from their base year values to reflect the effects of changes in the price structure of the economy. At this point, it should be remembered that the prices being used here include the cost of transportation and that the focus of the study is on the total economic effect of changes in the transportation system. The formula developed above provides a theoretical framework for determining the effects of such changes in transportation as may be represented as changes in cost. From a long-run point of view this would include all changes in transportation.

## H. Definition of Freight Nodes

The Econometric model described in this chapter requires that the state of Pennsylvania and its periphery be subdivided into a set of freight zones or nodes* which become the origins and destinations of all freight movements. A practical question arises as to the manner in which the nodes should be selected. Some guidelines on this problem are now proposed.

The model describes the flows of goods between the nodes of the State and its periphery. Thus, the more numerous the zones identified, the more complete will be the description of freight flows within the State. However, certain practical considerations limit the number of nodes that should be considered. For certain purposes it may be desirable to use the model to analyze traffic flows among as few as, say, four regions of the State. For other purposes, a more detailed analysis will be required. It seems likely, from rather cursory observation, that not more than 30 nodes need be identified for the State of Pennsylvania.** If this number is selected, it still remains to determine the precise boundaries of each zone.

Practical considerations of data availability will require that zones be defined in terms of counties. Thus, a zone will consist of at least one county, but may be a

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* A "node" is merely the point-representation of the geographic area called a "freight traffic zone."

**See the report by Franklin Institute Research Laboratories on Operational Project 5.

group of contiguous counties. The group should be in some sense homogeneous, and this requirement suggests that a formal methodology may be applied to determine the groupings. For this purpose, the methodology described by Berry* may be adopted if exacting rigor is desired. In any case, the choice of factors for measuring (and determining permitted) variability within zones is important. The Econometric Model itself suggests the choice of factors.

The framework for the Econometric Model contains the definition of a single production function for every industry within each freight traffic zone. Zones will in general contain many firms in the same industrial classification. This suggests that the more uniform the character of the firms in an industry, the better will the single production function describe the activity of that industry in the zone. Thus, the factors that differentiate among the activities of firms in the same industry become important measures of economic variability within the zone.

## I. Summary of Forecasting Strategy

The following steps are involved in developing the Econometric Model and using it for forecasting purposes:

1. Select the important zones in Pennsylvania that most reasonably represent the predominant centers of economic

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* Berry, B.J.L., "A Method for Deriving Multi-Factor Uniform Regions," Przeglad Geografrezny, Vol. 7, No. 2, 1961, pp. 263f. The regionalization techniques developed by Professor Berry derive from the theory of multivariate statistical analysis, and have been programmed into a quite versatile yet facile computer package.

activity and the origins and destinations of the most important traffic flows through the State.

2. Select the centers of economic activity outside the State of Pennsylvania that may best be defined as the sources and destinations of the State's import-export trade.

3. Select the commodity classification scheme that is to be used. It is suggested that the 2-digit SIC commodity classification be the basis of selection. For the transportation model it might be desirable in some cases to combine some of the 2-digit classes, and in others to use a finer breakdown.

An important consideration is involved in combining commodity classes. Commodities of quite different classes may have similar characteristics from the point of view of transportation, and this might suggest combining them for the purpose of transportation analysis. However, their production might involve quite different processes and input combinations. In this case, the combination of the two classes into one would do violence to the assumption of a single production function and, therefore, damage the predictive features of the model.

4. Collect base year input-output data to fill the columns and rows of a table such as Table VII-3, on p. 233 The data collected should be in money terms and also in physical units so that two tables may be constructed, one in terms of the appropriate physical units and the other in money terms. The two tables should be related to each other by

means of the definition:

$$Y_{igjh} = (p_{igjh} + f_{igjh}) X_{igjh}$$

where these terms are defined on pages 231 to 234. The arrangements of the columns and rows of the tables should follow the scheme set out in Table VII-4.

5. Compute the ratios $R_{igjh}$ defined at (VII-2), p. 234

6. For each column of X's in sections (a), (e), (i) and (m) arranged according to Tables VII-3 and VII-4, compute a set of ratios $X_{ig} \div X_{iH}$, where iH identifies the first non-zero entry in each of the segments of the column devoted to the respective inputs classifications. In the same way, compute the corresponding set of ratios $Y_{ig} \div Y_{iH}$. Using the technique described by relations (VII-59) through (VII-71), compute the ratios $\alpha_{ig} \div \alpha_{iH}$ and the respective $\beta$'s. These $\alpha$'s and $\beta$'s are constant parameters of the system.

7. For a given year and a proposed transportation system, obtain the expected transportation costs, $f_{igjh}$, as defined on p. 232. Using these transportation costs together with the expected prices, compute the set of sums:

$$p_{ig} = (p_{igjh} + f_{igjh}) \qquad \text{(VII-75)}$$

From these prices and the ratios of the $\alpha$'s computed in step (6), compute the ratios $r_{iH}$ by means of the formula given by equation (VII-70). It should be remembered that in the development of the formula (VII-70), as well as of the others used above, we dropped the subscripts which would have identified the particular firm for which the production

function was estimated. If the dropped subscripts are restored, we have:

$$r_{iHjk} = 1 \div \sum_{g=1}^{m'} \left[ \frac{\alpha_{igjk}}{\alpha_{iHjk}} \cdot \frac{p_{iHjk}}{p_{igjk}} \right]^{\beta_i / 1-\beta_i} \qquad \text{(VII-76)}$$

These r's have a one-to-one correspondence with the R's computed for the base year, and are the modified values of these ratios for the year for which predictions of commodity flows are to be made.

8. For the appropriate year, prepare forecasts of the export trade of Pennsylvania and of shipments to Federal, State, and local government agencies, both from industries within the State and from those outside the State. These forecasts must be by commodity and by node of origin and destination to provide the elements needed for the rows and columns of sections (b), (c), and (f) in Table VII-4.

9. From the forecasts prepared in step (8), prepare vectors G(b), g(f) and E as defined at (VII-12).

10. From such data as exists and/or land use plans, prepare the set of capacity constraints presented at (VII-16) and (VII-17).

11. Select some objective function Z, such as that at (VII-20) or (VII-22).

12. By means of a Linear Programming algorithm, such as I.B.M.'s MPS/360, find a solution to the problem of maximizing Z subject to the constraints developed in step (10) and the inequality $[I - r(a)]Y \leq G(b) + E$, where the terms of this inequality are, respectively, the matrix of r's developed

in step (7), and the forecasts of g(b) and E prepared in step (9).

13. The solution obtained in step (12) will be the forecasted total output of the various Pennsylvania industries at each node. These forecasts form a vector Y. This Y may then be used in the manner described in the methodology section to derive a forecast of the interindustry internodal flows of commodities for the State.

# APPENDIX VII-A
# DETERMINATION OF EQUILIBRIUM SOLUTION FROM GIVEN PRICE CHANGES

Suppose ratios $T_{igjh}$ are defined analogously to the ratios $R_{igjh}$ as follows:

$$T_{igjh} = X_{igjh} \div X_{jhoo} \tag{A-1}$$

For any industry (jh) these ratios are the inputs of real resources per unit output of real product. They are, therefore, technological coefficients in a production sense.

The generalization of (VII-28) for any industry (jh) in the input-output table would be:

$$X_{IGjh} = \frac{\alpha_{IGjh}}{p_{IGjh}} Y_{oojh} \tag{A-2}$$

where $Y_{oojh}$ is defined as the total cost of real inputs.

For any budgeted total cost the equilibrium output may be computed by substituting (A-2) into the production function given at (VII-23) so as to get:

$$X_{jhoo} = Y_{oojh} \prod_{i=1}^{n} \prod_{g=1}^{m} \left(\frac{\alpha_{igjh}}{p_{igjh}}\right)^{\alpha_{igjh}} \tag{A-3}$$

By substituting (A-2) and (A-3) into (A-1) we find that:

$$T_{IGjh} = \left(\frac{\alpha_{IGjh}}{p_{IGjh}}\right)^{1-\alpha_{IGjh}} \prod_{i \neq I} \prod_{g \neq G} \left(\frac{p_{igjh}}{\alpha_{igjh}}\right)^{\alpha_{igjh}} \tag{A-4}$$

Thus if the Cobb-Douglas production function is assumed to be the basis of equilibrium commodity flows in an input-

output table, the technological coefficients, T, defined at (A-1) are constants for any given set of prices. However, if any price should change the corresponding T will change and the new equilibrium value will be given by (A-4).

From the definition (A-1) it follows that:

$$X_{igjh} = T_{igjh} X_{jhoo} \tag{A-5}$$

Summing both sides we get:

$$\sum_j \sum_h X_{igjh} = \sum_j \sum_h T_{igjh} X_{jhoo} \tag{A-6}$$

The left-hand side of (A-6) is the sum of all shipments from industry (ig) to all other industries. But this sum does not account for total production since shipments to governments and to other countries are not included. Let the sum of all such additional shipments by any industry (ig) be defined as $S_{ig}$. With this definition (A-6) may be written as:

$$X_{igoo} - S_{ig} = \sum_j \sum_h T_{igjh} X_{jhoo} \tag{A-7}$$

There will be an equation of this type for every industry represented by a row of data in the input-output table. This system of equations may be represented in matrix notation as:

$$X - TX = S \tag{A-8}$$

or

$$(I - T) X = S \tag{A-9}$$

For any given set of technological coefficients, T, and for any given level of values for the vector S, the solution for

(A-9) will be:

$$X = (I - T)^{-1} S \qquad \text{(A-10)}$$

Suppose, now, data for some base period have been compiled into input-output tables of the type given at Table VII-1 and VII-2. Then the set of $\alpha$'s for the production function may be estimated by equation (VII-2), since it has been shown that the equilibrium value of $R_{igjh}$ is $\alpha_{igjh}$. If some prices should change from those of the base period, a matrix of new equilibrium T values may be computed by equation (A-4). This matrix may be inserted into (A-10) along with any given S to determine a new equilibrium solution for X and, therefore, for all entries in a revised input-output table.

# VIII
# THE ABSTRACT MODE MODELS

## A. Introduction

As discussed in the previous chapter, the Econometric Model forecasts interindustry internodal economic transactions, both in terms of tonnage and dollar value. Thus, it simultaneously estimates commodity flows for all freight zone (node) pairs, as well as estimating each zone's economic and demographic activity levels.

At this point, two models operate upon the Econometric Model's various outputs, with the objective of establishing the pattern of origin-destination flows, by mode, for both freight and passenger traffic. Recall that, while the Econometric Model endogenously estimates the O-D patterns of commodity flows as well as determining the spatial distribution of industrial activity, it merely establishes the spatial distribution of population and personal income in its demographic aspect. Thus, the Passenger Demand Model addresses the three problems of trip generation, distribution and modal split, while the Freight Modal Split Model merely addresses the last problem. The rationale for this approach is given in chapter VI.

Both of these models draw heavily upon the concept of an "abstract mode" (hence the chapter title). As discussed in chapter V, a methodology which intends to treat existing and anticipated transport technologies is at a total loss if it is structured in terms of institutional modes *per se*.

Rather, it must characterize distinct technological alternatives in terms of their service attributes, and not in terms of what the public calls these alternatives. By example, the air mode is not used because it operates above the ground; it is used because of its relative speed, comfort and other advantageous service attributes.

The original formulation of the abstract mode model, developed by Mathematica for the Northeast Corridor Transportation Project, treated all three problems of generation, distribution and modal split simultaneously, and similar models were wrought for both passenger and freight demand. As articulated in chapter VI, we too believe that the classical methodology of transportation planning dissects the transportation decisions of firms and households far more than is necessary and sensible. Our Passenger Demand Model, like the original Mathematica model, analyzes the generation, distribution and modal split problems simultaneously for this reason. Insofar as freight demand by mode is concerned, we have extracted the modal choice problem from the generation and distribution problems, since we believe the simultaneity of decision-making in that context is more meaningfully characterized as described in the previous chapter (the Econometric Model).

The remainder of this chapter discusses these two models, which operate in parallel between the Econometric Model and the Network Simulation Model. For purposes of continuity with the previous chapter, we first discuss the Freight Modal Split Model (section B); section C is reserved for the

Passenger Demand Model. Section B is considerably longer, for two reasons. First, during the discussion of freight modal split, we must introduce the reader to the novel "abstract mode" concept. The original formulation is discussed in the freight context, but the principles cited are directly applicable to the Passenger Demand Model. Second, because we have abandoned the traditional sequence of passenger traffic models in favor of the simultaneous approach, very little of section C is devoted to review of past work.

## B. Freight Modal Split

### 1. Previous Work

A search of literature pertaining to modal split and transportation economics has revealed that very little work has been done in the area of freight modal split, and that no freight modal split models of the size and nature required for a regional planning project have been tested by applications to real data. The lack of information in this area is a result of two factors: a) the need for a model of this type has not been recognized until recently; and b) the data required to calibrate and test such a model are unavailable. The current section gives a brief description of the pertinent literature and how it applies to the freight modal split problem.

Merrill J. Roberts* has done work on modal coordination and transportation costs. Although his major concern in

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* Merrill J. Roberts et.al., Intermodal Freight Transportation Coordination: Problems and Potential, Graduate School of Business, University of Pittsburgh, December, 1966.

the cited publication was the economic value of changing rates and providing multimodal service, the expected use of the new service was included in the economic evaluation. The market value of the service was described by the shipping rate charged, plus a measure of service qualities. If the sum of these variables was lower than that for existing modes, the new service would attract traffic. The service quality includes such things as transit time, reliability of service, and costs associated with the distribution system that are not considered in the rate. The Freight Modal Split Model must consider factors that influence modal choice. It is, therefore, important to define the factors that are included in "service quality" quantitatively, so that a model for predicting modal split can be developed.

It has been suggested that the determination of a dollar value for time would provide a method of evaluating alternate transportation modes. If the value of time is known, time and dollar cost can be added together to provide one variable. An article written by Beuthe and Moses* considers the influence of time on the split between rail, water and truck transportation. The value of time is defined as the interest of money tied up in the product while it is in transit. In an example presented in the paper, an interest rate of 6.51% was used. This figure was obtained from the Board of Trade;

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* Michel V. Beuthe and Leon N. Moses, "The Demand for Freight Transportation: The Influence of Time," in Transportation: A Service, New York Academy of Sciences, 1967, pp. 61-65.

however, the appropriate interest rate to use in different situations will depend upon the product's market characteristics.* In the model, the value of time plus the cost of shipment and the cost of production are subtracted from the price at destination to determine profit. The mode chosen is that which provides the largest profit. The effects of service quality other than time are not considered explicitly by the model.

The National Cooperative Highway Research Program Report Number 33, Values of Time Savings of Commercial Vehicles, gives values of saved time as they apply to those supplying the transportation services. This is not applicable to the modal split problem, because time saved in delivery of a product does not necessarily imply increased revenue for the producer, which is the assumption used to evaluate the value of time in this report. Also, the value of time saved would be different for each commodity being shipped, requiring an evaluation of the value of time for each commodity considered. It is convenient to apply a dollar value to time for the economic analysis of alternate transportation systems. However, the use of this concept in modal split analysis seems to be unjustified, due to the difficulty of obtaining this information.

Models have been developed that deal with specific transportation problems. However, of those examined, the methods

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* The interest rate of 6.51% times the value of a shipment of produce would not adequately determine the value of time for this commodity. In this instance, late delivery implies a total loss of the shipment's value.

of analysis were not general enough to be applicable to the problem of freight modal split in Pennsylvania. An example of such a model is one proposed by J. L. Milder* to evaluate military logistics problems. Several basic assumptions used in the development of this model are not valid for non-military applications: 1) there is an infinite supply of goods at origin points; 2) there is a given supply of vehicles of different modes, all under the direction of the decision-maker; and 3) the desired solution is the most efficient utilization of the available transportation. The adoption of this model would require that the above assumptions be changed to fit non-military objectives, implying a thorough mathematical redevelopment.

Two articles appearing in Highway Research Record No. 175 were directed towards determining the highway share of freight transportation. Church** shows that modal split between highway and rail can be predicted if the commodity type is known, the size of shipment is known, and the distance between origin and destination is known. The results obtained using Church's method are shown to be accurate to within five percent, as applied to the examples used in the report. The article by Buhl*** shows that the size of a firm,

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* J.L. Milder, A Stochastic Dynamic Multimode Transportation Model, prepared for the United States Air Force Project RAND, published by the RAND Corporation.

** Donald E. Church, "Impact of Size and Distance on Intercity Highway Share of Transportation of Industrial Products," Highway Research Record No. 175, Washington, 1967.

***Walter F. Buhl, "Intercity Highway Transport Share Tends to Vary Inversely with Size of Plant," ibid.

as measured by the number of people it employs, can be used to predict modal split if the commodity type is known.

A report prepared by Mathematica* for the Northeast Corridor Transportation Project presents three separate models for predicting the demand for transportation by freight shippers. Two of the models will be presented here briefly while the third, based upon the Quandt-Baumol "abstract mode" model for determining passenger demand for transportation**, will be presented in greater detail in the following section of this report.

One of the Mathematica models is referred to as "the macro-economic approach", and is a system of simultaneous equations that are calibrated using data in various degrees of aggregation. The first equation uses socioeconomic variables to predict the total demand for transportation in the study area during a given time period. The last equation uses results obtained from the previous equations to predict the flows of goods from specified origins to specified destinations, by mode. The formulation of the model has not been developed in the report; each equation merely gives the dependent variable as a function of possible independent variables. It would be necessary to arrange data in five degrees of aggregation for the calibration process as well

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* Mathematica, Studies on the Demand for Freight Transportation, prepared for Northeast Corridor Project, U.S. Department of Transportation, Washington, D.C., Contract #7-35120, August 1967.

**R.E. Quandt and W.J. Baumol, "The Demand for Abstract Transport Modes: Theory and Measurement," Journal of Regional Science, Vol. 6, No. 2, Winter, 1966.

as placing constraints on future demand projections. At present, the model has not been developed enough to allow a detailed examination. However, the model has been rejected for use in this planning effort because of the apparent difficulties in its calibration and the difficulty of extracting that portion of the model that deals with freight modal split.

The "micro-economic approach" predicts the demand for transportation using equations developed from inventory theory. Information is required about demands for goods at destination, inventory costs, shipping costs, and the value of time for the commodity in question. In the Mathematica report, doubt is expressed about obtaining the necessary data input for this model. The "micro-economic approach" has been rejected as an alternative in this planning effort because it seems unrealistic to obtain the necessary inventory data required by the model, and because it requires the determination of a dollar value of time. The latter objection has been amplified earlier in the report.

All of the Mathematica models handle the generation, distribution and modal split tasks as one task. While this approach seems justified in handling the passenger demand problem, the aggregation of tasks for freight movements appears to be artificial. While the decision by a person to make a trip depends upon the cost and time required to make the trip, the generation of goods to be shipped depends upon the market value of the good. Once the decision to produce has been made, the decision to ship has been made. Modal

choice enters as a separate decision, connected with the decision to ship only as transportation costs affect prices of products or associated shorter-run profits. It therefore seems more realistic to handle modal split as a separate task in the procedure of determining the traffic volumes that will flow on the transportation network.

Another model based on inventory theory is "The Shipper Preference Model", developed by F. M. Graves* for the U.S. Bureau of the Budget. The model was developed using only data on I. C. C. Docket 7027, paint and related articles, for the year 1959. Only shipments of 20,000 lbs. or more were considered. The model incorporates a stochastic demand model along with inventory information to estimate the size and kind of shipments made. The shipper's preferred mode is then based only on the relative shipping costs. This model was felt to be inadequate because of the data requirements (demands, inventories, etc.) and because the split was made on the basis of cost, without consideration of other factors that influence mode choice.

The above review points out several variables that should be considered for predicting modal split. They are: 1) the cost of transportation to the shipper; 2) the door to door transit time; 3) distribution costs associated with particular modes that are not included in the charge to the user; 4) a measure of reliability; 5) the type of commodity

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* Graves, F.M., "The Shipper Preference Model," Papers of Sixth Annual Meeting, Transportation Research Forum, 1965.

being shipped; 6) the distance between origin and destination; 7) the size of the shipment; and 8) the size of the producer of the goods. A freight modal split model that considers all these variables in their proper relationship to each other should be a valuable modal split predictor.

## 2. The Abstract Mode Approach to Freight Modal Split

The most advanced work presently available on many aspects of regional transportation planning has been done under the auspices of the Northeast Corridor Transportation Project. One report prepared for this project, Studies on the Demand for Freight Transportation*, represents the most novel efforts to analyze freight movements over a transportation network. Two of the models presented in that report have been discussed briefly in the preceding subsection of this report. The third model is presented here in much greater detail, because the Freight Modal Split Model proposed for use in PennDOT's planning effort is a modification of this approach.

This abstract mode approach contains features of both the micro-economic and macro-economic approaches discussed earlier, but is more realistic than either of them with regard to the required data (the micro-economic approach) and the calibration procedure (the macro-economic approach). All three models predict the demand, by mode, for freight

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* Mathematica, Studies on the Demand for Freight Transportation, Prepared for the Northeast Corridor Transportation Project, U.S. Department of Transportation, Washington, under Contract 7-35120, August 1967.

transportation between specified origin-destination pairs. The approach taken in this effort is to accomplish the freight generation and distribution tasks using the Econometric Model, and to extract that portion of the abstract mode model that pertains specifically to modal split.

The pure abstract mode approach predicts the tons of freight to be shipped from node i to node j by mode k in a specified time period, $T_{kij}$, by considering eleven variables:

$$T_{kij} = f(P_i, P_j, Y_i, Y_j, M_i, M_j, N_{ij}, H^b_{ij}, H^r_{kij}, C^b_{ij}, C^r_{kij}) \qquad \text{(VIII-1)}$$

where $T_{kij}$ = Tons shipped by mode k from node i to node j

$P_i, P_j$ = Population of node i, node j

$Y_i, Y_j$ = Gross regional product of node i, node j

$M_i, M_j$ = Industrial character index for node i, node j

$N_{ij}$ = Number of modes available for use between node i and node j

$H^b_{ij}$ = Least time in transit of all available modes between node i and node j

$H^r_{kij}$ = Relative time in transit (with respect to $H^b_{ij}$) of mode k between node i and node j

$C^b_{ij}$ = Least transportation cost of all available modes between node i and node j

$C^r_{kij}$ = Relative transportation cost (with respect to $C^b_{ij}$) of mode k between node i and node j

The variables that are used to determine modal split are the industrial character indices*, $M_i$ and $M_j$, the number of

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* The industrial character index would give an indication of the commodity type to be shipped between the nodes in question.

available modes, $N_{ij}$, the relative time, $H^r_{kij}$, and the relative cost, $C^r_{kij}$. The population of the nodes, the gross regional products, and the least time and cost variables are included in the formula above to predict the freight generation and distribution.

Given the tons of freight to be shipped from node i to node j in a given time period, $T_{ij}$, the freight modal split equation becomes:

$$P_k(T_{ij}) = f(M_i, M_j, N_{ij}, C^r_{kij}, H^r_{kij}) \qquad \text{(VIII-2)}$$

where:

$P_k(T_{ij})$ = percentage of freight shipped from node i to node j by mode k

A constraint must be placed on this equation such that $\sum_k P_k(T_{ij}) = 100$. This constraint provides that the sum of the amounts shipped by each mode is equal to the total amount shipped. Using the mathematical formulation of a generalized gravity model*, a possible equation for this model becomes:

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* The equation of the gravity model used to distribute trips in urban transportation studies is usually expressed as:

$$T_{ij} = T_i \left(\frac{S_j}{D^x_{ij}}\right) \Big/ \sum_{k=1}^{n} \left(\frac{S_k}{D^x_{ik}}\right)$$

where:

$T_{ij}$ = Trips from node i to node
$T_i$ = Trips generated in node i
$S_j, S_k$ = Attraction factor of node j, node k
$D_{ij}$ = Distance or travel time between node i and node j
$n$ = Number of nodes
$x$ = Coefficient depending on trip type

Generalizing the equation:

$$T_{ij} = \alpha_0 T_i^{\alpha_1} S_j^{\alpha_2} D_{ij}^{\alpha_3} \left(\sum_{k=1}^{n} S_j\right)^{\alpha_4} \left(\sum_{k=1}^{n} D^x_{ik}\right)^{\alpha_5} \quad (\alpha_4, \alpha_5 < 0)$$

$$P_k(T_{ij}) = \alpha_0 M_i^{\alpha_1} M_j^{\alpha_2} N_{ij}^{\alpha_3} (H^r_{kij})^{\alpha_4} (C^r_{kij})^{\alpha_5} \qquad \text{(VIII-3)}$$

There are several advantages of this model over previous modal split models. Using the abstract mode approach, a mode is described by its characteristics rather than by its name. This allows for the examination of new modes by merely specifying the travel time and cost of the mode without referring to its physical form. Notice that a new service provided by an existing mode, or a new combination of existing modes, is treated as a new mode if the time and cost characteristics are changed. A further advantage of this approach is that it is possible to test the model internally. If data are available on four modes, the model can be calibrated on three of them and then used to predict the use of the fourth. Comparing the results obtained from the model with the data on the fourth mode will provide a check on the accuracy of the results.

The abstract mode approach evaluates the effects of transportation time and cost on the modal split decision. This information is useful in evaluating the effects of future transportation investments or policies and how they will effect the economy of a region. The cost of transportation can also be used to predict the distribution of future freight flows.

The relative values for time and cost are used to indicate the advantage of one mode as compared to the most desirable mode in that category. The advantage of this method of describing the variables is that only one equation

is required for all nodes considered. The use of absolute values instead of relative values would require that the equation be calibrated for each origin-destination pair.*

The mathematical form of the equation (i.e., linear in the logarithm) is based on the form of a generalized gravity model. The gravity model has been used in urban transportation studies and gives reasonably accurate results when applied to real data. More recently, passenger movements have been examined using the abstract mode model developed for passenger transportation** in several mathematical forms. The results indicate that the log-linear form provides the best fit to the data.

There are several disadvantages of the freight modal split model as presented above. While it is indicated in the Mathematica report that commodity type should be considered, no published effort was made to adapt the model to consider this variable. Because of the variation in both shipping rates and the importance of time over different commodities, this omission is a serious one. The shipping rate and transit time are also a function of the size of shipment. Again, this problem was pointed out but the only solution

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* Assume the equation has been calibrated using absolute costs and times for one origin-destination pair and that all the coefficients are positive. Using the same origin and a destination further from the origin than the first destination, the costs and times by one mode would increase. Using these values in the calibrated equation would imply an increase in the percent of use regardless of the cost and time changes of any other mode, while it is possible that another mode has gained an advantage because of lower relative costs and times for the second destination.

**Mathematica, op.cit., Volume III.

suggested was to handle "carload lot" (truckload lot) shipments as a different mode from "less than carload lot" (less than truckload lot) shipments. This breakdown is not sufficient to explain the variation of the time and cost variables over the large range of shipment sizes.

Mode reliability is handled, to some extent, implicitly by the model. The cost of transportation includes insurance costs which can be considered to be a measure of average loss due to theft, breakage, or lost shipments. The model in its present form, however, does not include a discriminating measure of reliability with regard to the service provided by a mode. For some shippers, it is important that shipments leave on time and/or arrive on time. The number of times a day that a shipper can obtain service may also influence the choice of modes. The model should include measures of the frequency of service offered by the mode in question as well as the quality of that service.

An assumption implied by the use of the abstract mode model is that modal split decisions are based upon the shipper's transportation economics. Such is not always the case. Some companies employ a reciprocity policy in order to foster goodwill and encourage sales.* Some companies ship by a given mode simply because they are not aware of alternative services. It is assumed that these

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* A steel company might ship by rail, even though it is cheaper to ship by motor carrier, because the railroad is a big user of steel. It is assumed by the steel company that profits from sales to the railroad will more than cover the cost differential incurred by using the railroad.

situations do not arise frequently enough to seriously effect the results obtained from the model.*

In summary, their freight modal split model, as extracted from the "pure abstract mode model," has the flexibility to consider new transportation technology, allows for the examination of the effects of transit time and cost on modal choice, and is presented in a mathematical form that has been used with acceptable results in other aspects of transportation planning. The model neglects the effects of commodity type, shipment size and service reliability on the modal split decision. Because the model is based upon transportation economics, it assumes that all shippers base the modal split decision upon economic criteria. This assumption, while not valid in all cases, is the most rational approach to the problem of freight modal split and has been used as the basis for the model proposed for use in PennDOT's transportation planning effort.

## 3. The Proposed Model

In order to perform the task of freight modal split as part of an integrated forecasting model system, there are two important criteria that the model must satisfy. First, it must be compatible with the Econometric Model, whose output becomes input for the modal split model. Second, the output of the Freight Modal Split Model must correspond to the eventual output of the passenger model to the extent that

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* Data aggregation tends to iron out intangible factors of opposing effect, in any event.

these outputs are to be combined to obtain the vehicle flow volumes that will obtain on the transportation network.

The basic output of the proposed Econometric Model will be the amount, in tons, of commodity i that will be shipped from node g to industry j in node h, $X_{igjh}$. The total planning methodology requires that these node to node flows of commodities provided by the Econometric Model be allocated to various modes of transportation. These modal allocations are the responsibility of the Freight Modal Split Model. It should also be pointed out that once the freight flows are aggregated into the form of $X_{kgh}$ (i.e. tons of goods from node g to node h by mode k), the output will be compatible in character* with the output of the passenger model (i.e., person trips from node to node by passenger mode).

Considering the nature of the shipper decision process, the data constraints, and existing related work on freight modal split, multiple regression analysis provides the best technique for developing a Freight Modal Split Model. The advantages of multiple regression analysis in this situation are that it allows all relevant variables to be considered and determines the importance of each variable with respect to the other variables (indicated by the regression coefficients for each variable). These coefficients cannot be

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* A coarser system of traffic zones (nodes) is used for freight analysis then the Edwards and Kelcey system adopted for passenger analysis. For any mode to be processed by the Network Simulation Model, then, the $X_{kgh}$ must be reduced to the finer zone system.

determined until the model is tested against real data, i.e., until the model has been calibrated.

The proposed model is based upon the Mathematica "abstract mode" model presented in the preceding section of this report. The mathematical formulation of the proposed model is basically the same as the original abstract mode model; however, some of the variables have been changed and the method of applying the model has been altered to fit the requirements of this effort. The form of the regression equation is as follows:

$$P_k(X_{igjh}) = \alpha_0 R_k^{\alpha_1} C_k^{\alpha_2} T_k^{\alpha_3} F_k^{\alpha_4} \qquad \text{(VIII-4)}$$

with the constraint:

$$\sum_k P_k(X_{igjh}) = 100 \qquad \text{(VIII-5)}$$

where:

$P_k(X_{igjh})$ = Percentage of $X_{igjh}$ that will be shipped by mode k

$R_k$ = Reliability of mode k

= percent of deliveries made on schedule or shipper rating (1=poor, 2=good, 3=excellent)

$C_k$ = Relative cost by mode k

$$= \frac{\text{lowest rate by all available modes}}{\text{rate by mode k}}$$

$T_k$ = Relative transit time by mode k

$$= \frac{\text{lowest time by all available modes}}{\text{time by mode k}}$$

$F_k$ = Relative frequency of service by mode k

$$= \frac{\text{frequency of service by mode k}}{\text{best frequency of service}}$$

$\alpha_{0,1,2,3,4}$ = Coefficients to be determined by the regression analysis.

The method of applying the model after it is calibrated is as follows. The amount of good i to be shipped from node g to industry j in node h in one year, $X_{igjh}$, will be obtained from the Econometric Model. If the rates for this commodity are based upon volume rather than weight, the volume will have to be determined at this point. The weight or volume will then be divided by the number of shipments made in one year, $N_{igjh}$, to obtain the average size of shipment. With this information, the rate per ton or per unit volume will be determined by all modes available for service between nodes g and h. This will be accomplished by referring to a table that shows rates for different shipment sizes by different modes between nodes g and h. The relative transportation costs can then be determined by taking the lowest cost of the available modes as the common numerator and the costs of each mode as denominators. Information on transit times will come from the path-tracing feature of the Network Simulation Model. Following the same procedure used for determining relative costs, the relative times will be calculated. Relative service frequencies and reliability will be calculated on the basis of exogenous information. For each of the available modes, $P_k(X_{igjh})$ will then be determined, with the constraint that $\sum_k P_k(X_{igjh})=100$. $X_{kigjh}$ will then be determined by multiplying $X_{igjh}$ by $P_k(X_{igjh})$. The process will be done for each origin-destination pair and for each commodity classification. Appendix VIII-A contains a simple example, carried out with hypothesized data, as an aid to the reader's understanding of the process.

Based upon the available related literature* and a knowledge of the shipper decision process, there are eight variables that are particularly germane to the freight modal split task. It should be noted that where a high degree of interrelationship (correlation) exists among variables, the regression process allows the replacement of two or perhaps more variables with one highly correlated variable without much effect on the accuracy of the results. Cogent empirical analysis requires careful investigation of possible variables for the regression equation in order to uncover interrelationships that will reduce the required number of variables. The remainder of this subsection considers each of the eight variables in detail in an effort to disclose the rationale for their inclusion in the formula, or the theoretical basis by which their inclusion may not be necessary.

One of the most important variables to the modal split decision is the cost of the transportation service to the shipper, or the price the shipper is required to pay for the movement service. There is little doubt that present patterns of freight movement are influenced in most cases by the rates charged by the carriers. It should be noted that shippers are influenced by the quality of service provided by different carriers, and that such considerations may cause shippers to choose a mode that has a cost disadvantage. These service quality considerations will be treated below.

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* See subsection 1 above, "Previous Work."

Also of importance is the fact that the cost differential between modes affects the modal split decision in varying degrees, depending upon the commodity type.

For any given commodity, the transportation cost will be directly influenced by the size of shipment and the distance between origin and destination. The effect of distance* on rates is attributable to the variable costs of carriers, e.g. fuel costs, which increase with distance. The size of shipment affects costs because of economies experienced by the carriers in terminal costs with larger shipments. The most common evidence of this effect is the carload lot (CL) and the less than carload lot (LCL) rates offered by railroads. Motor carriers often offer more complex rate structures giving cost advantages for larger shipments.

As noted in the literature review, one freight model uses distance and size of shipment to help allocate shipments among modes.** The proposed method of applying the model uses these variables to determine transportation cost. Based upon this consideration and the above discussion, transport cost can be used in the regression analysis in place of the distance and the size of shipment. It should also be pointed out that transport cost is more compatible with this effort than the size and distance variables. The Econometric Model

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* It should be noted that costs do not increase in direct proportion to distance but increase at a decreasing rate.

**Donald E. Church, op.cit.

which generates and distributes commodities among nodes is transportation cost sensitive, i.e., commodities are allocated among nodes based to some extent on transportation costs. In addition, the evaluation of alternate transportation investment proposals requires a cost analysis based upon total user costs, part of which (i.e., the cost of moving freight) will be available from this model.

One of the models examined in the review subsection used the size of the firm producing the goods to be shipped as a variable.* The results of this study show that, for a given commodity classification, the percent shipped by highway decreases with an increase in the size of the firm. In other words, the larger the firm, the less shipped by highway. The advantage of a model of this nature is that the data requirements are modest. Gross yearly output and firm size as measured by the number of employees are the only inputs required to make the model functional. The report indicated, however, that while reasonable results were obtained when applying this method to a large number of firms shipping the same commodity, the results showed considerable variance when applied to individual firms. In this modeling effort, while some aggregation will occur when two or more separate plants produce the same good in the same node, there are instances when one firm may be the only shipper of a commodity in a node. This makes the

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* Walter F. Buhl, op.cit.

use of the firm size variable questionable, and consequently it is not included in the proposed modal split model.*

Transit time has been used in several of the models examined as a consideration for carrier selection. The importance of time to shipments of perishable commodities and to "rush order" shipments is quite apparent. Transit times are important to other commodities as well, because long transit times may necessitate large inventory levels at destination points, which requires warehouse space. Consequently, many firms pay high shipping costs for faster transportation in order to minimize inventory expenses. The significant increase in the use of air freight, despite rates that are two or three times higher than those for surface transportation, is evidence of the importance of time.

Several studies reviewed in previous sections of this report have attempted to handle the transit time variable by determining a dollar value for time, which could then be added to the transportation cost variable to obtain a total transportation "cost" to the shipper. The problems involved with calculating such a "cost" have led to the use of an average value of time, which is then applied to all situations. This approach does not consider the variation in value of time for different goods, nor the varying importance of time in different regions of the study area, nor the fact

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* If the data become available, the firm size variable could be tested for significance and might provide some additional accuracy to the modal split prediction.

that the value of time is not necessarily constant throughout the day. For example, time will be of more value per unit measure for color television sets than for construction sand. The value of time to a shipper in Philadelphia may be different from the value to a shipper in Mount Union, even though they are shipping the same commodity. Furthermore, for some shipments, the time between 5:30 p.m. and 8:00 a.m. has a value near zero, since the receiving establishment is not open for business during that time period. Given the importance of time to the modal split decision, and the problems created by using a dollar value for time, the regression equation for modal split will handle time as a separate variable.

Related to the transit time of modes is their reliability regarding delivery schedules, or the variation which occurs with respect to transit time. One of the factors that affects required inventory levels is the variability in expected delivery time. The probable reliability of a carrier regarding delivery time variations affects the level of safety stock held by receivers. Some shippers are willing to use a slower mode of transportation in order to obtain more reliable service, and thus reduce the change of having a "stock out" situation while holding lower levels of safety stock.

Reliability or variability in delivery time is the most difficult variable to describe quantitatively. Further, previous research efforts have indicated the difficulty of

obtaining delivery time information.* Most shippers appear to have only an impression of service reliability at destinations, since little detailed information is recorded. These two factors together make reliability easier to deal with in the regression equation than would be the case if another formulation were used. A possible definition of this variable is the percent of deliveries made on schedule. An alternative approach to this problem is to use two dummy variables in conjunction with a rating or classifying scheme (poor, good, excellent).** The rating approach would be consistent with data availability and would allow consideration of service reliability. It should be noted that planners will have to use their judgment in the rating procedure, based upon experience obtained from working with related data.

As is noted in the discussion above, transit time and service reliability are important to the shipper because they affect the total cost of using a particular mode. These costs are referred to as non-transport costs or distribution

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* Roberts, Merrill J. et.al., op.cit.

**Replace $R^{\alpha_1}$ with $X_1^{\alpha_5} X_2^{\alpha_6}$ in equation (VIII-4), where:

for "poor": $X_1 = 1$, $X_2 = 1$ (multiplies equation by 1)

for "good": $X_1 = 10$, $X_2 = 1$ (multiplies equation by $10^{\alpha_5}$)

for "excellent": $X_1 = 1$, $X_2 = 10$ (multiplies equation by $10^{\alpha_6}$).

Notice that the effect of this procedure is to evaluate the effects of different reliabilities in the regression process while not imposing an arbitrary scale factor into the rating scheme.

costs. The levels of such costs, as reflected through warehousing or inventory costs, are very important to some commodities. A further measure of service quality that influences the modal split decision is the frequency of service. This variable has been included in the equation because of the effects of service frequency on handling and inventory costs and on the convenience to the shipper. Also, its use in the equation is quite compatible with the transit time and reliability variables.

The discussion above has referred to the fact that the relative importance of the variables will be different for different commodities. This factor will be taken into account by the proposed method of applying the model. A regression analysis will be run on each commodity classification. This means that if ten commodity classifications are used, there will be ten equations for predicting modal split. Using this approach, commodity characteristics that affect modal split will be accounted for implicitly by the calibration process and will not have to enter the regression equation as explicit variables.

## 4. Comparison to the Original Mathematica Model

It is important to reiterate the fact that the abstract mode approach to freight modal split was adopted from the Mathematica model, "the pure abstract mode approach" to the demand for freight transportation. The authors did not intend that their model be used just as a modal split model, but rather that it be used to accomplish the generation,

distribution, and modal split tasks simultaneously as one task. The Freight Modal Split Model was extracted from the Mathematica model because of the advantages of this approach in handling the modal split task, and to provide a base from which to explain the proposed model. The following discussion is intended to show differences between the proposed model and the extracted portion of the Mathematica model, and is not a critique on the original work.

The advantages of the abstract mode approach to freight modal split have been incorporated in the proposed model. By using some different variables and changing the method of applying the model, several of the weaknesses of the extracted model have been strengthened.

The proposed model retains the abstract mode method of describing modes by their characteristics, allowing for examination of the effects of future technological and organizational improvements without reference to the physical form of these improvements. The calibration process evaluates the relative importance of time and cost to the shipper, which can then be used in the distribution analysis (inherent to the Econometric Model) and for economic evaluation of proposed transportation improvements. The use of relative values for the variables has been retained in the proposed model, which generalizes the equations developed in the calibration process for all origin-destination pairs. The mathematical form of the proposed model is the same as that employed in the Mathematica abstract mode model, and thus

affords the same advantages with respect to the calibration process and computational ease.*

One of the disadvantages of that abstract mode model is that the effects of commodity type on the modal split decision are not considered in any detail.** The industrial character of the nodes might give some indication of the commodity type flowing between the nodes. However, these indices will be gross aggregates (particularly in large cities) and will give only generalized results. The method of calibrating the proposed model implicitly accounts for the effects of commodity type. The model will be calibrated on data stratified by commodity type, providing a different regression equation for each commodity classification. Using this procedure, differences in the importance of time and cost among different commodities will be considered. Also, different rates charged for different commodities can be delineated and will give a more realistic value for the transportation cost variable than could be obtained using an average cost for all commodities. A further advantage is that characteristics of commodities that affect the modal split decision that are not considered by the variables in the regression equation are considered by the calibration process. A minor disadvantage is that the procedure requires

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* A more complete review of these points was presented in subsection 2 above.

**The comments, throughout this chapter, on the original Mathematica model are based entirely on published documentation of their work.

a different equation for each commodity classification, which increases the number of times the model must be applied to obtain the desired results. However, the fact that commodity type is considered should greatly improve the modal split predictions, and does not require defining the industrial character of the nodes by means of a generalized index.

Another improvement in the proposed model is that service reliability at both origin and destination is included as affecting the modal split decision. The frequency of obtaining service at the origin by mode k, $F_k$, measures the convenience available to the consignor. The reliability of delivery or the percent of deliveries made on schedule is a measure of convenience to the consignee. The importance of the reliability factors to a firm has been pointed out in the previous subsection of this chapter. The inclusion of these variables in the freight modal split equation should improve the accuracy of the predictions.

The proposed model uses shipment size and distance to obtain the transportation cost or the rate paid by the shipper. Because of the variance of cost with shipment size (a three-fold increase in the cost per ton between a 1000 lb. shipment and a 30 ton shipment by rail), the average cost by commodity type is meaningless to the shipper. Using shipment size and commodity type to determine transportation cost will provide a much more accurate measure of the actual cost paid for the transportation service.

The original formulation of the abstract mode model included the number of modes available between any two nodes; this variable is not retained in the abstraction. The rationale behind the use of this variable involves the hypothesis that the range of transportation options available has an induction effect upon total transportation demand. Since we are concerned here only with modal split, total O-D demands having been calculated by the Econometric Model, there is no need to include the variable. Besides, this induction effect is far less probable in freight transport than it is in passenger transport.

The proposed model, as well as the extracted abstract mode model, are built upon the assumption that modal choice is based upon transportation economics. While instances can be cited where this assumption is not true, it is doubtful that their occurrence will be frequent enough to affect the results of the model.

In summary, the proposed Freight Modal Split Model incorporates the advantages of the abstract mode approach. Some steps have been taken which presumably will improve predictive power over that provided by the original abstract mode model, by introducing different variables and changing the method of applying the model to the region under study.

## 5. Implementation of the Model

Up to this point in the presentation of the model, discussion has been directed towards the development of the model and the value of it as a predictor of freight modal split. While it is difficult to discuss the practicality

of the approach until some attempt has been made to apply the model to real data, there are some problem areas that have been recognized during the development of the model. The purpose of this subsection is to point to anticipated problems in implementation, with specific reference to the type and form of data that will be required.

Besides the collection of data, there are two tasks that must be performed. Both deal with the problem of transportation costs. First, a study should be conducted to determine present rate structures to and from all origins and destinations to be considered in the study. The importance of cost in determining modal split has been pointed out in earlier subsections. The purpose of the study should be to organize rate information into tables that give the cost of transportation by mode, by commodity type, by origin and destination, and by shipment size. The rate data should not be difficult to obtain for common carriers; however, putting the information into a usable form is a formidable task. Specific rates for commodity types must be aggregated into rates for the commodity classification scheme to be used. If ten commodity classifications are to be used and one table is to be prepared for each origin point, each table would have a number of entries equal to ten times the number of destinations times the numbers of weight groups chosen to differentiate shipment sizes.

The second study should be directed towards the prediction of future rates. Competition, changes in volumes of

goods shipped, Federal and State regulations, and technological improvements are just a few of the factors that affect changes in rates charged for transportation services. Some conclusions or decisions must be reached about values to use for future transportation costs. The importance of this task cannot be overemphasized. Accurate future costs are not only necessary to predict freight modal split, but are also important because of the role of costs in the distribution process (via the Econometric Model) and the evaluation of proposed changes in the system.

Calibration of the model will require an extensive data collection program. It should be pointed out, however, that the data collection program must be coordinated with information requirements of other models to be used in the planning effort. The first requirement of the modal split model is the shipment size data. Average shipment sizes are required to determine transportation costs. The Econometric Model intended for use in conjunction with this model needs information on yearly shipments between plants. The inclusion of either the number of shipments made or the average shipment size for these yearly flows would be sufficient to satisfy the requirements for the Freight Modal Split Model.

The remaining information requirements for the variables in the model are the mode service characteristics. Information about transit times must be obtained for each mode and for each origin-destination pair. The availability of service at the origin is also required and may be defined as

the frequency at which service is obtainable. Also, the reliability of obtaining deliveries within quoted timetables is required. Two definitions of this variable have been presented earlier, and the information obtainable will dictate the definition used. The preferred form is the percentage of deliveries made on schedule. This information may be available from those providing the transportation service or those who use the service. Finally, data will be required that describe freight flows by commodity type, origin and destination, and the mode of transportation used (see section VI-C). This information will be used as the control for calibration purposes.

## C. Passenger Demand Model

The function of the Passenger Demand Model, which operates in parallel with the Freight Modal Split Model, is to estimate the flows of all passengers between all origin-destination pairs and by all modes. As discussed in chapter VI, this model simultaneously accomplishes the trip generation, distribution and modal split tasks which are treated sequentially in popular transportation planning practice. The same "abstract mode" principles discussed throughout the earlier sections of this chapter are applied to the passenger problem, with some analytical modifications to the original Mathematica passenger demand model developed for the Northeast Corridor Transportation Project.

Attention should be given immediately to the fact that two different areal unit systems are proposed for freight

traffic analysis and for passenger traffic analysis. Because of the relatively long average haul of commodities compared to average passenger trip length, and in order to keep the recommended goods movement survey within realistic proportions, a more coarse system of zones (nodes) is to be used in the Econometric Model and the Freight Modal Split Model than in the Passenger Demand Model. While we purposefully leave a precise delineation of freight traffic zones for the implementation effort, we have established that the passenger zone system shall correspond exactly to the 149 zone system for Pennsylvania which was used in the Edwards and Kelcey study. Because the Passenger Demand Model requires population, personal income and employment estimates by this zone system, the values of these socioeconomic variables as forecasted by the Econometric Model need to be factored down from the freight zones to the passenger zones. This item is discussed in the next subsection, after which the proposed Passenger Demand Model is presented.

### 1. Conversion of Socioeconomic Variables to Passenger Zones

As part of its output, the Econometric Model shall yield forecasts of population, personal income and employment (by industrial sector) for each of the freight traffic zones or "freight nodes." These zones are to be determined by a preliminary regionalization analysis of existing county data. As stated in the previous chapter, the total number of these county aggregations may range from fifteen to thirty or forty, depending on finalized attitudes toward commodity detail.

We strongly recommend working toward the upper bound of this range, at the expense of some commodity detail, in order to delineate origin-destination patterns as meaningfully as possible.

Assuming this relatively large number of freight zones, which stands roughly in a 1:4 ratio to the passenger zones, transport-insensitive prorating techniques should suffice to deduce socioeconomic activity levels for the passenger zones. To exemplify, suppose Allegheny County is one freight zone, which includes seven passenger zones defined by the Edwards and Kelcey study. The question of how transportation improvements between these seven zones might affect their relative levels of population and employment can only be answered by blowing the County up to a scale which depicts a reasonably detailed County network. By and large, this sensitivity will be oriented to highway transportation characteristics. However, only a handful of short links in the Statewide highway network fall within the County. The Statewide traffic pattern will not be very sensitive to improvements in these links.

Given these considerations, and given our desire to take maximum advantage of existing practices in the Commonwealth, we recommend that the zonal allocation strategy used by the Edwards and Kelcey study* be applied for this

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* Edwards and Kelcey, "Socio-Economic Trends and Forecasts," Interim Report No. 2, Pennsylvania Statewide O & D Study, April 1965.

purpose. The methodology for deriving zonal population and employment levels is spelled out quite clearly in the cited report. The only modifications required would be a stratification of employment by industry type and a linear regression analysis of personal income versus population at the zonal level (income data shall be abstracted from the 1960 Census). This strategy will yield estimates of population, personal income and employment by industry for each passenger zone, thereby establishing the socioeconomic data required for the Passenger Demand Model (see subsection 3 below).

## 2. Background on Passenger Travel Models

A consideration of passenger movement among a system of zones immediately gives rise to a whole host of questions to be answered, such as the number of trips originating in each zone, the number of trips interchanged between each zone pair, the mode or modes of travel utilized by the trips, and the like. To handle such a problem, the first reaction is to consider the application of the various phases of the transportation planning process generally used in urban areas. A schematic of the major phases of this process is shown in Figure VIII-1.

Before either adopting or rejecting this approach for a Statewide analysis, it may be well to briefly review the major aspects of each of the four phases of the process, that is, Generation, Distribution, Modal Split, and Assignment. These four phases, as they have developed over the last decade or so, generally have been treated separately, the output of one being the input of the next phase.

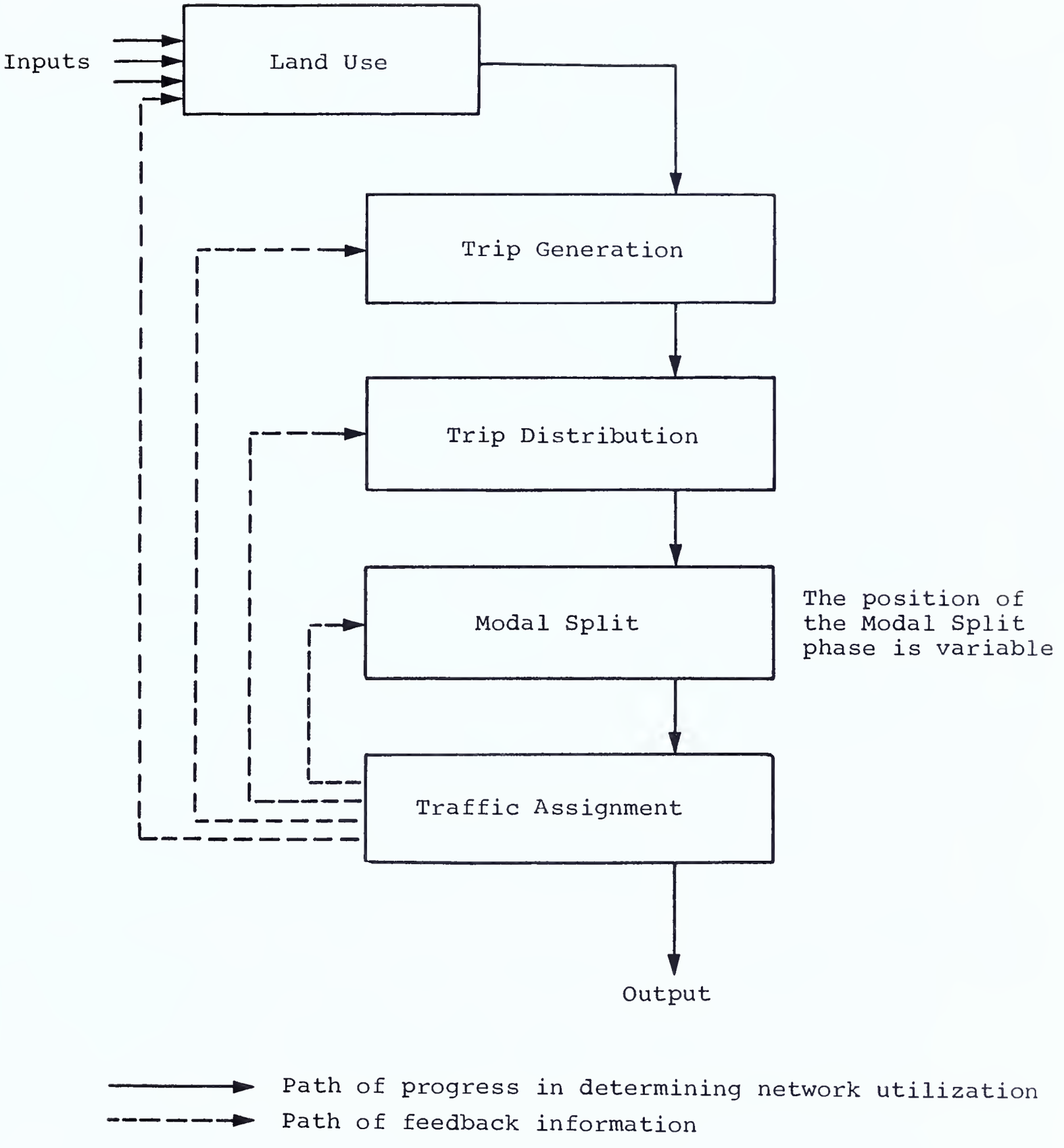


Figure VIII-1. Schematic of Transportation Planning Process

The generation of trips in an urban zone has generally been related to various land use and socioeconomic variables, such as number of dwelling units, distance from the central business district (CBD), number of automobiles per household, number of licensed drivers per automobile, family income, net floor area used for commercial or industrial use, etc. One or more of these variables is typically related to the number of trips generated in a given period of time per each household or per acre, or some other appropriate unit of measure. The general form of the relationship is usually*

$$T_i = \alpha_1 X_{i1} + \ldots + \alpha_r X_{ir} + \ldots + \alpha_m X_{im} + E \qquad \text{(VIII-6)}$$

where $T_i$ = number of trips per unit of measure generated in zone i (i=1,2,.....,n)

$X_{ir}$ = the $r^{th}$ of m variables having significance in the generation of traffic in zone i (i=1,...,n; r=1,...,m)

$\alpha_r$ = coefficient expressing the weight or significance of the variable (r=1,2,...,m)

E = constant or error term.

The parameters $\alpha_r$ are determined by multiple regression analysis.

The output from (VIII-6), i.e., $T_i$, is then used as an input for the distribution model. Of the various distribution models developed, such as the Growth Factor model, the Gravity model, and the Opportunity models, all can be represented by the general expression:

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* The notational policy followed with regard to areal units in this chapter is to denote freight zones by g and h, and to denote passenger zones by i and j.

$$T_{ij} = T_i \cdot P(A_j) \quad (i=1,2,.....,n;\ j=1,2,.....,m) \qquad \text{(VIII-7)}$$

where $T_{ij}$ = number of trips moving from i to j

$T_i$ = number of trips generated in i

$P(A_j)$ = distribution factor representing the relative attraction of zone j for trips i, weighted by the resistance to travel from zone i to zone j.

It can easily be seen that each of the various distribution models attempts to evaluate the distribution factor $P(A_j)$.

Once the number of trips that will be interchanged between any two zones has been determined, a modal split model is usually employed to determine the percentage of trip traveling by private auto. Variables usually considered as significant in this model are number of autos per household, family income, trip purpose, ratio of travel times, and cost of transit service. Other variables also have been considered in studies for specific areas, with some degree of correlation found.

The general form of the modal split relationship can be expressed as

$$P(T_{kij}) = D - [\Theta_1 X_1 + \ldots + \Theta_\ell X_\ell + \ldots + \Theta_m X_m] \qquad \text{(VIII-8)}$$

where $P(T_{kij})$ = percentage of total trips going by mode k between zones i and j

$X_\ell$ = variable having significance in the selection of a mode ($\ell$=1,2,3,.....,m)

$\Theta_\ell$ = coefficient expressing the weight or significance of the variable ($\ell$=1,2,3,.....,m)

D = constant representing the maximum percent using any mode.

The parameters $\Theta_\ell$ are determined, again, by regression analysis. The total number of trip interchanges between any two zones by each mode becomes

$$T_{kij} = T_{ij} \cdot P(T_{kij})$$

where $T_{kij}$ = number of trip interchanges between zone i and j by mode k

$T_{ij}$ = total trip interchanges between zones i and j

$P(T_{kij})$ = percentage of total trips going by mode k between zones i and j.

Once the number of trips between each zone pair by each mode is determined, the assignment model allocates the trips to the various elements of the network that exist for each mode. Since each mode does not have access to all of the elements of the networks of each mode, separate networks are constructed for each mode and the assignments of trips to each respective network is usually done independently of assignments to other networks. This is usually the case even when two or more modes (buses and autos) have common elements (streets) in their respective networks. The feedbacks indicated in Figure VIII-1 represent revisions in link resistances (e.g., travel times), accomplished during the assignment process to reflect the congestion effect of high volumes.

This four-model approach evolved in the first generation of urban transportation planning studies and has gathered a loyal following during the past decade. Even then, it must have been clear that the types of decisions made by households and people, as characterized by the four separate models, are

much more interrelated than this traditional methodology allows. As argued in chapter VI, a simultaneous model which integrates two or more of these steps offers a very attractive alternative, not only because it makes more sense theoretically, but also because it eliminates cumbersome iterative cycles.

Quandt and Baumol* considered such a problem in their Technical Paper No. 4 for the Northeast Corridor Transportation Project. They developed an abstract model for the generation and movement of trips among various areas in a region. The formulation of that model was as follows:

$$T_{kij} = \alpha_0 \, P_i^{\alpha_1} \, P_j^{\alpha_2} \, Y_i^{\alpha_3} \, Y_j^{\alpha_4} \, M_i^{\alpha_5} \, M_j^{\alpha_6} \, N_{ij}^{\alpha_7} \, f_1(H) \, f_2(C) \, f_3(D)$$

where $P_i, P_j$ = population of nodes i and j (in millions)

$Y_i, Y_j$ = mean or median incomes of nodes i and j

$M_i, M_j$ = institutional or industrial character indices of nodes i and j

$N_{ij}$ = number of available modes between nodes i and j

$f_1(H)$ = effect of travel time H

$= (H_{ij}^b)^{\beta_0} \quad (H_{kij}^r)^{\beta_1}$

$H_{ij}^b$ = best (least) travel time between nodes i and j of all available modes

$H_{kij}^r$ = ratio of travel time by fastest mode to travel time by kth mode

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* Quandt, Richard E. and William J. Baumol, "The Abstract Mode Model: Theory and Measurement." Technical Paper No. 4, Northeast Corridor Transportation Project, Mathematica, Princeton, New Jersey, June 1966.

$$= \frac{H^b_{ij}}{H_{kij}}$$

$f_2(C)$ = effect of travel cost C

$$= (C^b_{ij})^{\gamma_0} \quad (C^r_{kij})^{\gamma_1}$$

$C^b_{ij}$ = best (least) cost between nodes i and j of all available modes

$C^r_{kij}$ = ratio of travel cost by best mode to travel cost by kth mode

$$= \frac{C^b_{ij}}{C_{kij}}$$

$f_3(D)$ = effect of departure frequency

$$= (D_{ij}{}^b)^{\delta_0} \quad (D^r_{kij})^{\delta_1}$$

$D^b_{ij}$ = best departure frequency between nodes i and j by any mode

$D^r_{kij}$ = ratio of departure frequency by best mode to frequency by kth mode

$$= \frac{D^b_{ij}}{D_{kij}}$$

$\alpha_0, \alpha_1, \ldots\ldots, \alpha_7, \beta_0, \beta_1, \gamma_0, \gamma_1, \delta_0, \delta_1$ = parameters estimated from regression analysis.

This formulation results in an equation that is linear in the logarithms of the variables, which has often been used in similar situations because of its relatively high correlation and because of its ease of manipulation.

The model in its present form has one peculiarity; that is, the introduction of a new mode increases the travel on some or all of the existing modes, regardless of the new mode's characteristics. This situation can be handled by the imposition of restrictions that will either modify or

eliminate one or more of the variables. Additional analyses* have been made on a large number of variants to the original model. Each variant, however, bears a resemblance to each other.

## 3. The Proposed Passenger Demand Model

Based on an evaluation of the intra-urban transportation models and upon the results of analyses performed on a family of functions describing inter-urban passenger travel, the following model is hypothesized for consideration to describe Statewide passenger travel via a particular mode:

$$T_{ijk} = \alpha_0 \, (P_i P_j)^{\alpha_1} \, (M_{ij})^{\alpha_2} \, (C^b_{ij})^{\alpha_3} \, (H^b_{ij})^{\alpha_4} \, (N_{ij})^{\alpha_5}$$

$$\exp\left[ \alpha_6 \left( \frac{\log C^r_{ijk}}{\log Y_{ij}} \right) + \alpha_7 \left( \frac{\log H^r_{ijk}}{\log Y_{ij}} \right) + \alpha_8 \left( \frac{\log D^r_{ijk}}{\log Y_{ij}} \right) \right]$$

where $T_{ijk}$ = number of trips by mode k between i and j

$P_i, P_j$ = population of zones i and j

$M_{ij}$ = institutional character index of zone i and j, such as value added by manufacturing or percent of employment in manufacturing

$C^b_{ij}$ = best (least) travel cost by any available mode between i and j

$H^b_{ij}$ = best (fastest) travel time by any available mode between i and j

$N_{ij}$ = number of modes available between zones i and j

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* Quandt, R.E. and K.H. Young, "Cross-Sectional Travel Demand Models: Estimates and Tests," Studies in Travel Demand, Volume III, Mathematica, Princeton, New Jersey, Prepared for Northeast Corridor Transportation Project, July 1967, pp. 39-74.

$C^r_{ijk}$ = ratio of cost by kth mode to best cost between i and j

$$= \frac{C_{ijk}}{C^b_{ij}}$$

$H^r_{ijk}$ = ratio of travel time by kth mode to fastest travel time between i and j

$$= \frac{H_{ijk}}{H^b_{ij}}$$

$D^r_{ijk}$ = ratio of departure frequency by kth mode to best departure frequency between i and j

$$= \frac{D_{ijk}}{D^b_{ij}}$$

$Y_{ij}$ = weighted average per capita income of zones i and j

$\alpha_0$ to $\alpha_9$ = parameters to be determined by regression analysis

The total number of trips interchanged between any two points varies as to purpose; ideally a stratification would be drawn for three types of trip purpose; work trips, business trips, and social-recreational trips. However, without substantial surveys, data are inadequate to do so.

The logic of including each of these variables is both intuitive and a result of previous studies and analyses. Each variable accounts for one or more of the aspects of passenger interchange among zones -- the number of trips generated in a zone, the number of trips interchanged between zones, and the mode of travel selected for each trip.

The population variable, P, has been found to be one of the most important factors in determining both the number of trips generated in a zone and the number of trips attracted

to a zone. The larger the population in either or both zones, the greater the number of trips generated and interchanged.

The institutional character index, M, is a variable reflecting the type of economic activity of a zone. In a general, qualitative sense it has been found that volumes of travel were related to this economic activity, ceteris paribus. For example, zones with predominant governmental or educational activity generate more trips per unit of population or income than do zones that are primarily agricultural or industrial. Other classifications of institutional character are financial, commercial, and balanced. There may possibly be others found to be significant, or the number of indices may be reduced. At this time there is not sufficient information to fix either the number of indices or their units of measure. Value added to manufacture, percent of employment in manufacturing, or an indicator based upon the percentage distribution of employment in various economic endeavors are all possibilities that need to be examined and established.

The inclusion of the institutional character index in this formulation, despite its omission or exclusion from other formulations, is based on the record of air passengers explained in relation to population at various cities. Some institutional character index, along with the other variables, therefore seems appropriate. High correlations achieved with some formulations that do not include an institutional character index can be said to explain the relationship of the

data upon which the correlation was based, but cannot, with assurance, be said to be a better or more correct formulation for prediction of future travel than those which include an institutional character index.

The least travel cost, $C^b$, has been included as one of the determinants of mode choice. This measure represents the direct, recognizable costs to the user involved in the transportation between points i and j. For commercial carriers this cost may appear to be fairly well defined and easy to determine, that is, the cost of travel is simply the fare charged by each commercial carrier. However, there are other travel costs that are directly associated with the commercial carriers, such as travel to and from the terminals, parking, bridge and highway tolls, and the like, which are less easily defined. The intent here is to include all legitimate costs associated with travel that an individual considers in making a selection of mode. Such things as depreciation and insurance on a private automobile may not be considered, but all direct operating expenses would be.

The fastest travel time, $H^b$, also has been included as one of the determinants of mode choice. This mode-specific measure has some effect on the distribution of trips as well as their generation but these effects may be difficult to isolate if, indeed, there is any need to isolate them.

The inclusion of the number of modes, N, can be considered as a first-order measure of accessibility. It will influence both the generation and distribution of trips between any two zones and, as will be shown later, possibly

have some effect upon increasing the number of trips by all modes when an additional mode is added. While this "induction" effect may not seem reasonable at first glance, there appears to be strong evidence of this happening within urban areas when new routes (if we draw an analogy between a new route and a new mode) are added to a system. The resulting traffic is always greater than that which would generally be expected from normal growth and that generated by the new facility.

The ratios of cost and travel time, $C^r$ and $H^r$, are included as additional determinants of mode choice. The effect of these ratios is modified by a measure of income of the areas, which acts as a surrogate characterization of variations in the value of time.

The departure frequency, $D^r$, is also a determinant of mode choice. The time of day of the scheduled commercial carrier departure is also considered to be an important factor in mode choice, especially if meeting appointments or connections with other carriers are involved. This, at least for the present, should be neglected, with the assumption that the schedules established by the commercial carriers will be in response to the greatest demand. A weighted average per capita income, Y, is included as a determinant primarily of mode choice but to some extent of generation.

One variable which has not been included but which has been considered at great lengths by others, and may indeed be sufficiently important to include here, is a measure of reliability of the mode. This reliability is considered to

be a measure of the ability to complete a scheduled trip within some arbitrarily specified limits. The rationale behind this consideration is experience with air travel in particular, where a mode choice of auto is made because of the lack of confidence that a flight will be completed because of bad weather. Consider experience in the Northeast Corridor during snow and other bad weather when planes are unable to fly; the railroads (because of their minimal susceptibility of weather) are overloaded with "fair weather" converts as a result of the reliability of railroads. The questions of what units to use and how to measure this variable are still unclear.

## 4. Implementation of the Model

The implementation of the Passenger Demand Model is very similar in concept to that of the Freight Modal Split Model. The dependent variables in both cases are identical except that one deals with person-trips while the other deals with commodity flows. Moreover, while the freight analysis will be stratified by commodity group (owing to the proposed investment in extensive surveys), the passenger analysis treats all trips in the aggregate. A stratification by trip purpose and by time of day would provide a more meaningful analysis (e.g., sensitivity to recreation planning could thereby be provided). Considering the availability of substantial passenger flow data (see chapters V and VI), the desire for this additional detail does not justify major survey work. As discussed in prior subsections, multiple regression analysis shall be applied to base-year data to

estimate parameters, in the same manner as was discussed for the Freight Modal Split Model.

The data requirements for this model calibration are as follows; note that all data specifications refer to the 149 passenger traffic zones defined by the Edwards and Kelcey "internal" study area. Required socioeconomic data include the population, average per capita income and employment (and/or value added) for each zone. The latter measure shall be detailed by type of industry, and will provide the basis for defining the institutional character of a zone. Besides the flow data discussed above (origin-destination person-trips by mode), the following network information is required:

(a) travel costs (operating costs, fares, tolls, and other direct costs) for each mode

(b) travel times for each mode

(c) distances between each i - j pair, to be used with costs and travel time when they are expressed as "per mile"

(d) number of available modes between each i - j pair

(e) service frequencies for each mode (where specific schedules do not exist, such as for automobiles and specific charter operations, equivalent frequencies can be used to approximate the availability of the mode).

For application in forecasting horizon-year flows, the same character of network measures is required for that year. Socioeconomic activity measures shall be derived from the forecasts of the Econometric Model by means of the allocation process discussed in subsection 1 above.

# APPENDIX VIII-A
# THE FREIGHT MODAL SPLIT MODEL: AN EXAMPLE

This appendix has been prepared to aid the reader's understanding of the process involved in the use of the Freight Modal Split Model. Data have been hypothesized for one yearly freight movement. The variables have been calculated and placed into the formula in their proposed form indicating the procedure intended by the design. The example assumes that the model has been calibrated with base-year data and is being used to predict the modal split of a future freight movement.

The origin is assumed to be 500 mi from the destination. This allows the use of a rate table from Appendix I, "Demand Analysis," Demand, Supply, and Economic Impact of Transport in the Keystone Corridor, by the Westinghouse Air Brake Company. Examination of the table shows that rates are given for "slow surface," "fast surface," and "air" modes of transportation. Assume that a value of $X_{igjh}$ of 300 tons has been obtained from the Econometric Model. From a prediction of the number of shipments to be made, $N_{igjh}$ is given as 20. From this information, the average shipment size is calculated to be 300 tons/20 shipments = 15 tons/shipment. The rates obtained from the rate table for commodity i between node g and node h show that the cost of transportation by each of the three modes is:

For slow surface: c = 3.7¢/ton-mi x 500 mi = $ 18.50/ton
For fast surface: c = 6.5¢/ton-mi x 500 mi = $ 32.50/ton
For air: c = 29.3¢/ton-mi x 500 mi = $146.50/ton

The estimated 1963 total rates in cents per ton-mile for a 500-mile shipment of varying size are:*

| Size of Shipment | Slow Surface | Fast Surface | Air |
|---|---|---|---|
| Under 0.5 tons | 20.5 | 37.0 | 77.0 |
| 0 - 4.9 tons | 13.5 | 26.0 | 55.0 |
| 5.0 - 9.9 tons | 7.1 | 14.0 | 39.0 |
| 10.0 - 14.9 tons | 4.3 | 8.0 | 32.0 |
| 15.0 - 19.9 tons | 3.7 | 6.5 | 29.3 |
| 20.0 - 29.9 tons | 3.5 | 5.5 | 26.0 |
| 30.0 tons and over | 3.0 | 5.0 | 25.0 |

The form of the cost variable is (the lowest cost by any mode)/(cost by mode k). The relative costs are calculated as follows:

For slow surface: $C_k$ = ($18.50)/($ 18.50) = 1.0
For fast surface: $C_k$ = ($18.50)/($ 32.50) = 0.57
For air: $C_k$ = ($18.50)/($146.50) = 0.13

Assume that the transport times obtained from the Network Simulation Model are 15 hr. for slow surface, 10 hr. for fast surface, and 3 hr. for air. Using the proposed form of the time variable, (the least time by any mode)/(the time by mode k), the relative times become:

For slow surface: $T_k$ = (3 hr.)/(15 hr.) = 0.2
For fast surface: $T_k$ = (3 hr.)/(10 hr.) = 0.3
For air: $T_k$ = (3 hr.)/( 3 hr.) = 1.0

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* Taken from the rate table of Appendix I, "Demand Analysis," Demand, Supply, and Economic Impact of Transport in the Keystone Corridor by the Westinghouse Air Brake Company.

Further, from exogenous information, the frequencies of service have been found to be 3 departures/ day for slow surface, 6 departures/day for fast surface, and 2 departures/ day for air. Again using the proposed form of the service frequency variable, (frequency by mode k)/(frequency by the best mode), the values of $F_k$ are:

For slow surface: $F_k = (3)/(6) = 0.5$
For fast surface: $F_k = (6)/(6) = 1.0$
For air: $F_k = (2)/(6) = 0.33$

The reliability variable (i.e. the percent of deliveries made on schedule) must also be determined from exogenous information. Assume that the reliabilities have been estimated to be:

For slow surface: $R_k = 0.70$
For fast surface: $R_k = 0.80$
For air: $R_k = 0.90$

Several observations about the procedure and the variables (which are ratios) should be highlighted at this point. First, notice that for each variable, an increase in value implies an increase in desirability. A decrease in the cost by mode k would imply an increase in desirability of mode k. $C_k$ increases if the cost of mode k decreases. A similar relationship exists among desirability, transit time, and $T_k$. For $F_k$, an increase in service frequency of mode k implies an increase in desirability of that mode. $F_k$ will increase if the service frequency by mode k increases. Reliability is described as a fraction which increases with desirability. The value of these relationships is that all exponents should

be positive, which would imply that the use of a mode should increase if the desirability increases.

Another important point to notice is that the common value used in all relative variables is not based on one mode. In the example above, the best cost is by slow surface, the best time is by air, and the best service frequency is by fast surface. This scales each variable to the most desirable value of the available modes and demonstrates the tradeoff faced by a shipper in determining the mode to use.

Remembering that the form of the regression equation is

$$P_k(X_{igjh}) = \alpha_0 \, R_k^{\alpha_1} \, C_k^{\alpha_2} \, T_k^{\alpha_3} \, F_k^{\alpha_4} \quad ,$$

the equations for predicting the percent of goods that will be shipped by each mode for this example become:

For slow surface: $P_k(X_{igjh}) = \alpha_0 (0.7)^{\alpha_1} (1.0)^{\alpha_2} (0.2)^{\alpha_3} (0.5)^{\alpha_4}$

For fast surface: $P_k(X_{igjh}) = \alpha_0 (0.8)^{\alpha_1} (0.57)^{\alpha_2} (0.3)^{\alpha_4} (1.0)^{\alpha_5}$

For air: $P_k(X_{igjh}) = \alpha_0 (0.9)^{\alpha_1} (0.13)^{\alpha_2} (1.0)^{\alpha_4} (0.33)^{\alpha_5}$

Note that for all modes $\alpha_0$, $\alpha_1$, $\alpha_2$, $\alpha_3$, and $\alpha_4$ are constant. The only constraint is that $\sum_k P_k(X_{igjh}) = 100$.

# IX
# THE NETWORK SIMULATION MODEL

## A. Introduction

The fourth and last model in the proposed forecasting model system is the Network Simulation Model, which follows directly after the Freight Modal Split Model and the Passenger Demand Model in the normal sequence of major analytical operations. Those prior models, together with the Econometric Model, provide estimates of origin-destination flows by mode for all passenger traffic in the aggregate and for various classes of commodities. The ultimate function of the Network Simulation Model is to estimate the manner in which all of this traffic will utilize the transportation network which intervenes between such origins and destinations. This result constitutes all relevant "direct effects."

The Network Simulation Model also takes on an intermediate role in the forecasting model system, whereby feedback to both the Freight Modal Split and Passenger Demand Models is provided under certain circumstances.* This operation becomes necessary in situations where the volume of traffic to be allocated to any network component(s) by the Network Simulation is likely to approach or exceed the prespecified capacity of such component(s). In such cases, the congestion effect of volume upon network measures such as travel time

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* This feedback is parallel in character to that shown from the "Traffic Assignment Model" in Figure II-5 of Part One.

must be accounted for, since such measures are used as independent variables in the two prior models. Through an iterative process, all three models are thereby exercised in concert to determine expected equilibrium flow patterns.

The emphasis here, of course, is on the role of the Network Simulation Model as a part of an integral forecasting model system for multimodal Statewide analysis. Before proceeding into technical discussion, the model's flexibility for other applications should be mentioned. In particular, given the requisite data, the entire model or parts thereof may be used for either single-mode or multimodal analysis at regional and local levels, particularly as part of the regional analysis approach proposed by the Bureau of Advance Planning. This flexibility is achieved through the use of a modular approach in the model design, whereby the partitioning of one mode from another is facilitated.

While the prior models already discussed address the questions of locational tendencies, choices of destinations and choices of modes, the Network Simulation Model is fundamentally concerned with patterns of route choice. As discussed in chapter VI, though to a certain degree all of these decisions may be simultaneous ones, we have judiciously separated the route choice problem from the other facets of behavior. By this assumption (which is softened by the iterative mechanism discussed above), the question of route choice may be analyzed separately for each mode of transport.* Obviously, the

* The exception to this rule is any case where more than one mode of transport uses the same physical facilities (e.g., both the auto, truck and bus modes use the same highway network). In this event, the three modes cannot be treated without consideration of their interactions.

significance of the route choice concept varies with the complexity of geometric configuration of any particular mode. Any mode which uses the highway system, for example, faces a relatively wide range of alternative routes. On the other hand, the Commonwealth's waterways network offers no range of route choice whatsoever.

The fact that the highway system offers a much broader choice of routes than any other technology is reflected in the state-of-the-art, as reported in Part One. The simulation of multimodal networks has little precedent. For highways, however, a rather well-developed approach known as "traffic assignment" exists. We draw upon this established approach very much in the model design, for three reasons. First, the highway network, by its relatively ubiquitous nature and its access function with respect to other modes, constitutes the most important part of the simulation. Second, unless relatively exotic, microscopic techniques are to be used, selected concepts of traffic assignment analysis offer the most convenient agent for analyzing other modes. Third, a battery of computer programs and manuals pertaining to traffic assignment has been fully developed by the Bureau of Public Roads,* thereby minimizing implementation problems. The latter two points reflect the dominant theme of the entire design, namely, a balancing between the costs and effects of implementing the proposed methodology.

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* Bureau of Public Roads, Traffic Assignment Manual, Washington, June 1964.

Two further points should be underscored before proceeding with the technical discussion. Throughout the previous chapters, the interfaces between the four models in the forecasting model system have been discussed in rather general terms. While it is not our purpose to attend to every last detail in the design, during the course of this chapter the interactions between the models will receive more definitive articulation. Postponing such elaboration to this point has been necessary because the feedbacks from the Network Simulation Model to the two prior models cannot be appreciated without an understanding of this last model.

The second additional point to be emphasized is that the definition of an appropriate abstract network is the most crucial task in implementing the Network Simulation Model. Once this step is accomplished, the remaining effort involves relatively straightforward extensions of the Bureau of Public Roads' program package plus a variety of simple list-processing features. Considerable attention is given to network definition in the discussion of the proposed model later in the chapter.

## B. Past Work

A variety of techniques for simulating traffic flows over a network have been developing during the last decade. Practically all such models have addressed the problem of allocating a given set of origin-destination flows to a network involving just one mode of transport. Furthermore, highway-based modes have received the bulk of attention,

prompted largely by the many urban transportation studies which have been conducted in recent years.

## 1. Models of Common Carrier Operations

By and large, the few attempts to simulate non-highway modes have little relevance to the proposed model design. Almost all of these techniques have focused upon one component of a single-mode network, taking a very microscopic, event-based simulation approach. Rail freight and airline terminal operations have received particular attention by various companies in the railroad and aviation industry. These techniques identify individual vehicles or groups of vehicles ("cuts"), and unit operations such as maintenance activities and/or classification policies. Allman* has simulated a system of seven freight classification yards for one rail carrier, and has suggested that considerably larger systems lie outside of projected computational capabilities. Miller** has implemented a linear programming model of the airline scheduling problem for a single-carrier network under a variety of simplifying assumptions. Like all models developed within the private sector, this one does not predict user route choice patterns; it searches for an operating policy which will maximize carrier profits. Again, any

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* Allman, W. P., "A Network Model of Freight System Operations," paper presented at Simulation of Railroad Operations, symposium sponsored by the Railway Systems Management Association, Chicago, March 1966.

**Miller, R. E., Domestic Airline Efficiency: An Application of Linear Programming, M. I. T. Press, Cambridge, 1963.

meaningful extensions* are anticipated to be very taxing in the computational sense. The simple point here is that any attempt to construct a microscopic (i.e., vehicle-identifying) computer simulation of a common carrier for an entire network lacks any precedent which might suggest a feasible undertaking for PennDOT. Our intention is solely to create an awareness of interesting research in these areas.

## 2. Concepts of Highway Traffic Assignment

In contrast to the lack of any precedent for a microscopic simulation of common carrier network operations which might be feasible for PennDOT, research in the highway planning context has been quite active. A wide variety of techniques have been advanced which address themselves to the so-called "traffic assignment" problem, whereby a set of origin-destinatio flows is allocated to a network of highway links on the basis of some route allocation hypothesis. As opposed to an event-based concept or time-dependent or stochastic approaches generally characterized by the term "simulation," these traffic assignment techniques are algorithmic heuristics which are based upon deterministic analytical concepts. We apply the term "simulation" to these techniques, inferring its broader meaning of modeling network flows satisfactorily.

The general structure of these models is as follows. An abstract highway network is defined in terms of a spatial

* The U.S. Department of Transportation is considering the pursuit of such extensions, though without any account of intermodal competition (see DOT Request for Proposal No. T8-542, "Intercity Transportation Effectiveness," March 1968).

arrangement of nodes, with links connecting these nodes where such access exists in the physical highway system. Some of these nodes are "loading nodes," which originate and terminate traffic. The typical traffic assignment model has two major inputs, namely, a table of origin-destination (O-D) flows for all pairs of loading nodes and a description of the network. The latter consists of two parameter values for each highway link, namely, capacity and some measure of impedance. Most frequently, either the average travel time at maximum flow (capacity) or the average minimum travel time is used as the impedance measure. All flows and link parameters generally refer to the "annual average daily traffic" concept* familiar to highway and traffic engineers, and refer to auto-equivalents (autos plus weighted trucks and buses).

The core of a traffic assignment model is its route allocation hypothesis. Given a set of routes available for any O-D pair, this hypothesis infers the relationship between the distribution of the O-D flow among those alternative routes and the average travel times of those routes. This concept implies two preliminary steps. First, some rule must be set forth for generating a reasonable number of routes (the "route generation rule") and defining those routes in terms of their respective link sequences. Second, some rule must be assumed for computing total route travel time from

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* or to factored peak volumes

the travel times of a route's member links (the "route time rule"). A minimum-path algorithm* applied repetitively (if more than one route is hypothesized**) or a multiple-minimum-route algorithm*** is generally used to generate alternative routes. Total route travel time is always assumed to be the sum of the times of individual links.

Route allocation hypotheses are of two general types. One approach is to assume an explicit mathematical relationship between route flow and route time. For example, one specific form is an inverse proportion function:****

$$q(k) = Q \cdot \frac{1/\omega(k)}{\sum_k 1/\omega(k)} \qquad \text{(IX-1)}$$

where $q(k)$ = flow over route k

$\omega(k)$ = travel time of route k

$Q$ = total O-D flow.

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* For example, see Bureau of Public Roads, Traffic Assignment Manual, op. cit.

** Some studies, such as the Chicago Area and the Pittsburgh Area Transportation Studies, assign traffic to only one route for each O-D pair.

*** See Bock, F., Kantner, H. and Haynes, J., "The rth Best Path Through a Network," paper presented at the Twelfth National Meeting of the Operations Research Society of America, Pittsburgh, Pa., November 1957; also, Mosher, W. E., Jr., "A Capacity-Restraint Algorithm for Assigning Flow to a Transportation Network," Highway Research Record No. 6, Highway Research Board, Washington (1963).

**** Irwin, N. A. and VonCube, H. G., "Capacity Restraint in Multi-Travel Mode Assignment Programs," Highway Research Bulletin 347, Highway Research Board, Washington (1962), pp. 258-289.

The other approach asserts that all drivers act so as to minimize their own travel time. Known as the Principle of Equal Travel Times, it may be stated as follows:*

> The [impedances] over routes not used are greater than or equal to the [impedances] over routes used. These [impedances over routes used] are all equal except in cases where a route has at least one [link] operating [precisely] at capacity. Such [capacitated] routes will have [impedances] less than or equal to the [impedances over all routes not involving a capacitated link].

Both of these approaches have intellectual appeal, though no one has derived any theoretical relationship between them.** Note that the case of only one route per O-D pair is compatible with both hypotheses.

At this point, it is convenient to draw a further distinction which introduces an important concept, the "capacity restraint." All assignment models eventually determine link flows by summing all of the route flows which pass through any given link; this information has obvious relevance to plan evaluation and refinement. Some models assume that link travel times are invariant with flow (more accurately, they assert that the expected traffic flows

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* Jorgensen, N. O., "Some Aspects of the Urban Traffic Assignment Problem," Graduate Report, Institute of Transportation and Traffic Engineering, University of California, 1963; p. 12. This concept is an extended version of the Equal Travel Times Principle as reported originally in Wardrop, J. G., "Some Theoretical Aspects of Road Traffic Research," Proceedings, Institution of Civil Engineers, vol. 1, part II, London, 1952.

**The mathematics of the proof become unwieldly before any opportunity for real insight is uncovered.

assigned to links will not vary over a sufficiently wide range to affect link travel times). Situations where assigned flows exceed link capacities are tempered manually (and unsystematically).*

More fashionable studies describe links with "capacity functions" which relate link travel time and flow mathematically, but in terms of the two link parameters mentioned above.** These models reflect more realistically the fact that as one highway route tends to attract more and more average daily volume (or average peak-hour volume, in some urban studies), other routes become more attractive. This "capacity restraint" concept is therefore a very useful tool, but of course has value only if the expected range of assigned route (and therefore link) flows is rather broad. This question must be addressed in the design of the PennDOT Network Simulation Model. Note that the capacity restraint concept reflects the broadest interpretation of the Principle of Equal Travel Times.

Those models which do not take advantage of the capacity restraint idea (called "free" assignments in transportation planning parlance) involve little more than a route generation algorithm (typically tracing just one route), the allocation of O-D flows to links in the generated routes, and the summarization of total link flows. Capacity-restrained models are

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* The Edwards and Kelcey study apparently took this approach.

**See Appendix IX-A for a summary of link capacity functions.

of two types, those which are integrated simultaneous equation models and those which employ an iterative strategy which gives a satisfactory approximation to observed link flows. Several versions of both types are reported in the literature. All of the simultaneous models are too unwieldly for the purposes of this design.* Models of the iterative variety are well-developed, and differ only in the capacity functions, loading strategies, and convergence tests used. Because of its availability and versatility, we describe only the Bureau of Public Roads' model here.

## 3. The Bureau of Public Roads Model

The BPR traffic assignment package as formally documented in the Traffic Assignment Manual** offers four basic options. Either a "diversion curve" technique or an "all-or-nothing" approach may be applied, and each may be operated with or without capacity restraint. The diversion curve concept is of no particular interest here, due to several shortcomings. The all-or-nothing approach, for both the "free" and the capacitated cases, is discussed here in some detail.

The uncapacitated version is quite straightforward, since it involves little more than the application of the

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* See Jorgensen, N. O., op. cit.; and Mosher, W. E., Jr., op. cit. See also Beckmann, M., McGuire, W. C. and Winsten, W. C., Studies in the Economics of Transportation, Yale University Press, New Haven, 1956, chapters 3 and 4.

**Bureau of Public Roads, op. cit.

minimum path algorithm to generate one (and only one) shortest route for each O-D pair.* Given these routes, O-D flows are allocated to the network as follows. One origin node is selected arbitrarily, and its flow to any given destination node is allocated to each link in the minimum path for that O-D pair. This allocation is accomplished for all destination nodes receiving traffic from the given origin node; flows on the network's links are accumulated as each O-D flow is so allocated. After the total traffic emanating from the given origin node has been so assigned to its "tree," the next origin node is selected and the process is repeated. The assignment is complete when all of the traffic from all of the origin nodes has been allocated to the network's links. The link flows accumulated throughout the entire process are then summarized. Mathematically, then, the "free" all-or-nothing assignment method involves the simplest of route allocation functions and a link flow summarization:**

$$q(k_{IJ}) = \varphi \cdot Q_{IJ} \qquad \text{(IX-2)}$$

where

$$\varphi = \begin{cases} 1 & \text{if } \omega(k_{IJ}) < \omega(\tilde{k}_{IJ}) \\ 0 & \text{any other } k_{IJ} \end{cases} \qquad \text{(IX-3)}$$

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* Technically, the algorithm generates a minimum "tree" for each origin node. Such a tree is a record showing the shortest routes and times of travel from a given origin node to all destination nodes in the network.

**The upper-case I and J notation refers to the ultimate origin and the ultimate destination nodes of a route.

$$q_\ell = \sum_I \sum_J q(k_{IJ}) \cdot \alpha_{k\ell}^{IJ} \qquad \text{(IX-4)}$$

$q(k_{IJ})$ = flow over route k between I and J

$Q_{IJ}$ = total highway flow from I to J

$w(k_{IJ})$ = total impedance of any route k serving IJ

$w(\tilde{k}_{IJ})$ = total impedance on any other route competing with k serving IJ

$q_\ell$ = total flow over any link $\ell$

$$\alpha_{k\ell}^{IJ} = \begin{cases} 1 & \text{if link } \ell \text{ is contained in route k serving IJ} \\ 0 & \text{if not} \end{cases}$$

The capacitated version of the "all-or-nothing" method is somewhat complicated, not so much because the concept of a link capacity function is introduced, but rather because an iterative strategy is employed. This strategy, as originally documented, proceeds roughly as follows. The "network description" input includes two parameters for each link: its capacity and its average travel time at zero flow. Trees are then built by the minimum path algorithm based on these travel times, all O-D flows are allocated to the links in their respective minimum routes, and total flows on each link are cumulated, just as in the case of a free assignment. By comparing these assigned volumes to the capacities of the individual links, a revised travel time is calculated for each link, to account for the congestion effect. The form of

the link capacity function used is as follows:*

$$\omega_\ell = \bar{\omega}_\ell \left[ 1 + 0.15 \left(q_\ell / c_\ell\right)^4 \right] \qquad \text{(IX-5)}$$

when $c_\ell$ = capacity of link $\ell$

$\bar{\omega}_\ell$ = "mean free travel time," i.e., the zero-flow limit of $\omega_\ell$

The precise manner of calculating revised link travel times (impedances) for the first iteration (i.e., the second tree-generation) is as follows. The volume assigned to any link $\ell$ during the first loading is entered into equation (IX-5) and a "balance" travel time is calculated. Then,**

> A new [travel time], based on an adjustment of the balance travel time, is then calculated for the next iteration to minimize the imbalance of volume on the link. Recognizing that changing the travel time on a link is likely to result in an inverse change in loading, the full effect of this change is moderated by using a [travel time] for the next iteration which is obtained by going only one-fourth of the way from the last assignment [travel time] toward the new balance [travel time]. It has been found that this method of adjustment eliminates large oscillations of loads on the links from one iteration to the next.

The new values of link travel times so calculated are then input into the minimum path algorithm to compute a revised set of minimum routes. As before, O-D flows are then allocated to the links in their respective minimum routes, and

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* ibid, p. V-20.

**ibid, p. V-21.

total link flows are cumulated during this allocation. Again, referring to (assigned volume)/(capacity) ratios, revised link travel times are calculated per equation (IX-5). This process may be continued for as many iterations as desired. Those who have used this approach have maintained, generally, that after three or four iterations the accuracy of the assignment does not improve appreciably.*

One matter which has not been clarified in the above discussion is the question of whether only the links in the last-generated minimum trees are loaded. Given, say, three iterations, the previous paragraph perhaps implies that only the links in the fourth set of minimum paths** are loaded. This is precisely how the BPR Manual reads, though it is rather vague. In other words, all routes generated during all but the last "pass" function only as intermediate steps toward an equilibrium solution of link flows, and only those links in the last-generated tree for any origin are loaded with that origin's traffic. Thus, this iterative strategy differs from a "free" version of all-or-nothing assignment only in that it calls for several preliminary iterations to "hone in" on most meaningful link travel times. The last iteration in the capacitated version of all-or-nothing

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* Convergence is defined by a subjective appraisal of the changes in summary flow (and/or impedance) statistics from one iteration to the next. When these changes are judged as "insignificant," the process concludes.

**i.e., the trees generated during the third iteration

assignment is no different from the free version discussed above.

While the all-or-nothing approach has proved to be a much easier tool than the diversion curve approach for complicated networks, its primary disadvantage is that it abandons the multi-route perspective. In most networks, any given O-D flow tends to be distributed over more than one route due to two reasons. First, because impedance generally increases with flow on any one route, other paths tend to become comparatively attractive as more traffic uses that route. Second, even if a total O-D flow is too slight to so affect route impedance, alternative routes are perceived differently by different persons. Thus, there is strong theoretical reason to believe that it is more proper to assign traffic to several routes rather than to use the all-or-nothing approach.

Indeed, more recent documentation of the BPR package suggests consideration of all routes generated in the iterative process. More specifically, it reports on the Bureau's recent tests of its programs, in which O-D volumes are loaded to links in all four sets of trees generated from four iterations. It is most convenient to explain this strategy by example.*

Figure IX-1 represents an origin node (1) and a destination node (2) which has a total flow of 400 trips. Three

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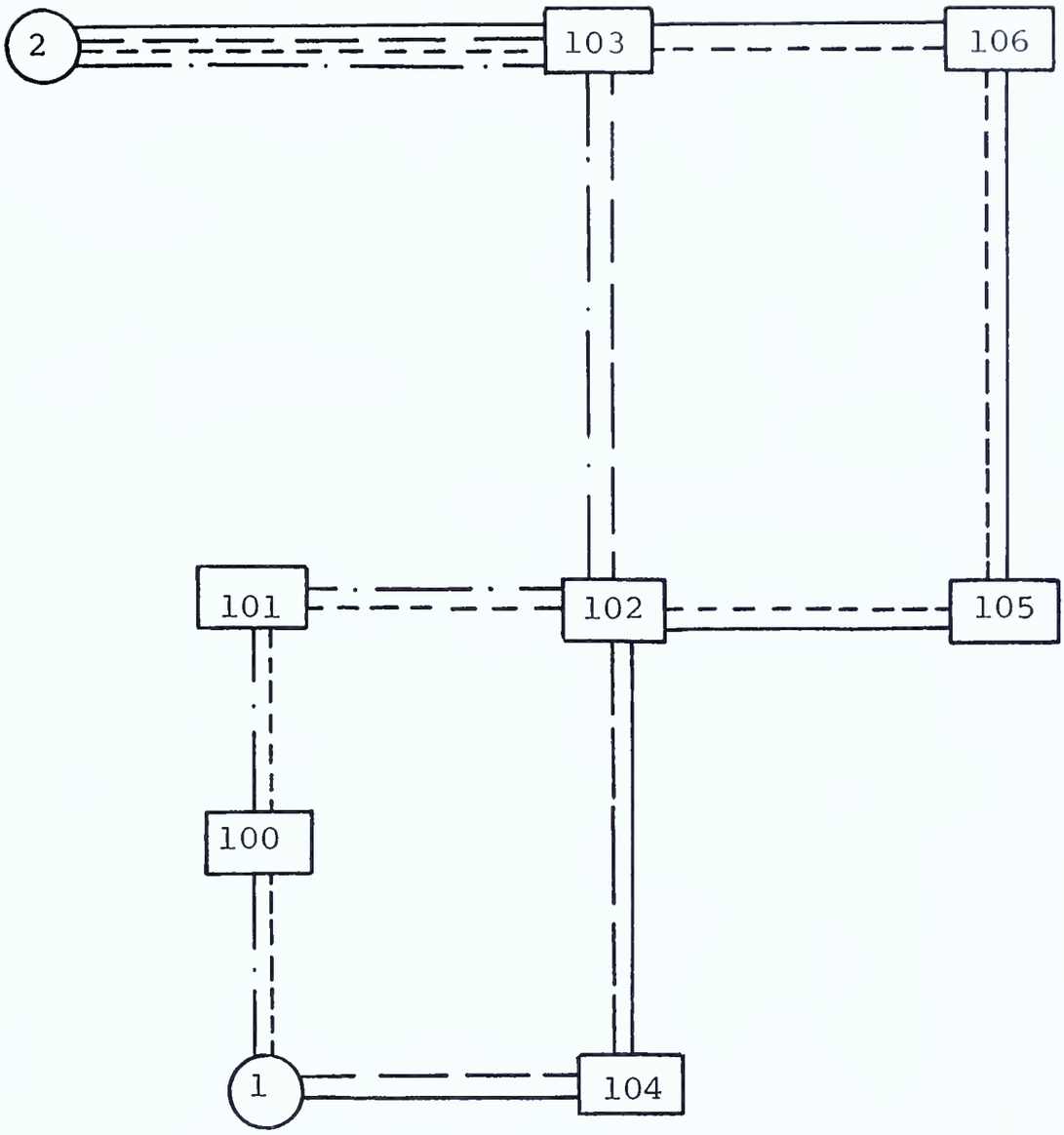
* This example is taken from Humphrey, T. F., "A Report on the Accuracy of Traffic Assignment When Using Capacity Restraint," paper prepared for the 46th Annual Meeting of the Highway Research Board, Washington, D.C., January, 1967, pp. 6-8.




Tree computed using speeds obtained in the traveltime study

Tree computed after first iteration of capacity restraint

Tree computed after second iteration of capacity restraint

Tree computed after third iteration of capacity restraint

1 Zone number

104 Node number

Figure IX-1. Illustration of the Multiple-Route BPR Assignment Model

iterations have produced four routes between ① and ② each resulting from an application of the minimum path algorithm for a given network description in each of the four "passes" through the capacity-restraint assignment process. In a very nebulous manner, all four routes are implicitly considered by the BPR approach, as Humphrey describes in terms of his example:

> Thus, four trees have been computed between zones 1 and 2, each using a different route through the network as illustrated in the diagram. Each time a tree was built 400 trips were assigned to that tree, the ratio of assigned volume to practical capacity was computed, a new speed was obtained for the next assignment, the next set of trees was built, and the process repeated for each iteration. The capacity restraint program has the ability to store the assignments made on each link for each iteration, and compute the <u>average</u> assigned volume made on that link. For example, link 2 to 103 has been used four out of four times that trees were computed; therefore, it has an accumulated total volume of 4 x 400, or 1,600 trips assigned to it. Similarly, link 100 to 101 has been used twice; therefore, it has an accumulated total volume of 2 x 400 = 800 trips assigned to it. A total of four assignments have been made to the network, each using a different set of trees. To obtain an average loading on the network, all accumulated volumes are then divided by four. This results in a final assigned volume on link 2 to 103 of 1,600 ÷ 4, or 400 trips; on link 100 to 101 the final assigned volume is 800 ÷ 4, or 200 trips. The same procedure applies to all links in the network to which trips have been assigned, and the capacity restraint program makes all computations.

Mathematically, then, the BPR approach described by Humphreys may be characterized as follows. Given all routes generated by the iterative process during which the link

capacity functions are brought to bear upon the repeated operations of the minimum path algorithm, the following route allocation relationship is applied to such routes:

$$q(k_{IJ}) = Q_{IJ} \cdot \frac{\tau(k_{IJ})}{\sum_{k} \tau(k_{IJ})} \qquad \text{(IX-6)}$$

when $\tau(k_{IJ})$ is the number of times route $k_{IJ}$ is generated by the iterative process.

Although this route allocation rule lacks meaningful behavioral interpretation, the current BPR approach may be more related to Wardrop's Principle than meets the eye. The basis for this statement is some recent research reported by Overgaard,* in which the application of a similar program was observed to converge toward an equal travel time situation. The assignment program he developed operates just as does the BPR approach described by Humphreys, except that he used the following form of link capacity function:

$$w_{\ell} = a^{(q_{\ell}/c_{\ell})^{b}} \cdot \bar{w}_{\ell} \cdot D_{\ell} \qquad \text{(IX-7)}$$

where $D_{\ell}$ is the length of link $\ell$ in miles. The parameter a expresses the ratio between impedance (travel time) at practical capacity and impedance at zero flow ($\bar{w}_{\ell}$). His findings are experimental rather than theoretical, but are

* Overgaard, K. R., "Urban Transportation Planning: Traffic Estimation," Traffic Quarterly, April 1967, pp. 197-218. See also "Testing a Traffic Assingment Algorithm," in Edie, L. C., Herman, R. and Rothery, R., Vehicular Traffic Science, Elsevier, New York, 1967, pp. 215-221.

nevertheless quite significant:*

> The test runs have given a practical indication that the...method used...can be considered an iterative procedure for solving the traffic assignment problem in accordance with the principle of equal travel times. A theoretical proof of the convergence would be welcomed.

## 4. Time-Structured Multimodal Assignment

Thus far in this section, we have drawn a broad distinction between microscopic simulation of common carrier operations and macroscopic highway traffic assignment. Between these very polarized approaches there lies one study** which has adapted the minimum-path concept of traffic assignment to a multimodal network, in a manner which simulates passenger movements through successive time periods.

From an analytical standpoint, the basic difference between highway transportation and the typical common carrier is that vehicular units in the latter case serve a variety of origin-destination demands over a route. For this reason, there is an obvious need for a carrier to establish schedules which coordinate the routing of vehicular equipment in reference to average inter-terminal transit times and the time variations of demand at each terminal in the carrier's network. Take as a hypothetical example the network shown

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* Overgaard, K. R., "Testing a Traffic Assignment Algorithm," op. cit., p. 219.

**This approach has been under development at the National Bureau of Standards, Technical Analysis Division, for the Northeast Corridor Transportation Project. Our comments derive from private communication with selected staff members.

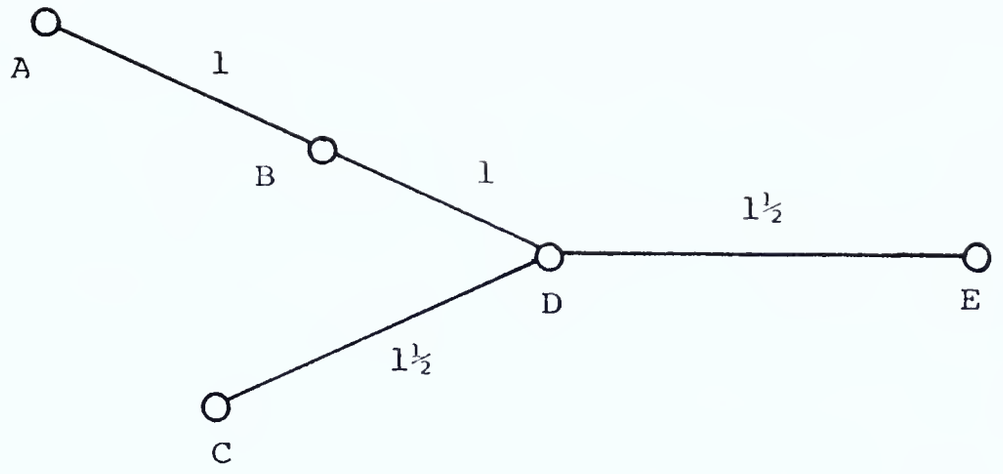


Figure IX-2. Hypothetical Example with All Originations Occurring Simultaneously

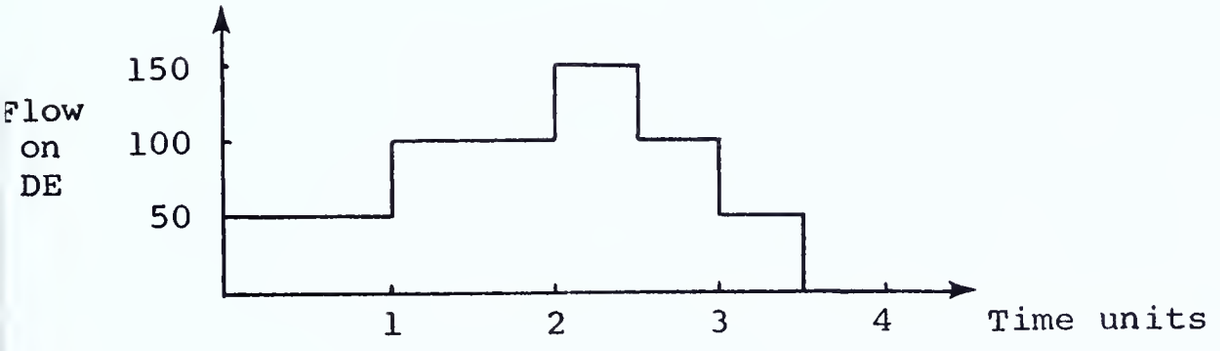


Figure IX-3. Time Pattern of Flow on Link DE in Hypothetical Example

in Figure IX-2. Assume that all flows originate at each node at the same time and are destined for E. Further assume that each node originates 50 units of flow and that the time units required to traverse each link are as indicated next to each link. Now let us examine the units of flow on link DE for 3½ time units. At time unit 1, an additional 50 units are on link DE from node B, and so on. This flow is plotted in Figure XI-3. One can readily see from this that the flow over link DE varies significantly with time. This example, simple as it is, points out the value of including a time-interval structure in a network simulation, and points out the obvious need for coordination of fleet routings. The example may be rendered much more complex simply by allowing the originating demands at each node to vary over time. As it stands, this simple case is equally applicable to highway transport, but has significance only in terms of temporal variations in link utilization patterns.

The National Bureau of Standards' model (and its several offshoot versions), while avoiding any microscopic considerations such as fleet or labor allocations, simulates flows over successive intervals of time and incorporates a schedule concept within this structure. Excellent computational algorithms have been developed which are compatible with different computing systems. Consideration of capacity restraints, however, is in an embryonic stage. The model assumes that thorough data on the time-patterns of origin-destination flows by mode are given.

## C. The Proposed Model

Having reviewed the salient features of past approaches to the network simulation problem, the proposed model and its rationale can now be presented in appropriate perspective. This section begins with a discussion of key issues peculiar to the Pennsylvania situation and the assumptions which evolve from that situation. Next, the matter of defining an abstract network in accordance with these assumptions is singled out because of this task's crucial role in the simulation. The third subsection presents the Network Simulation Model itself in terms of its analytical operations.

### 1. Key Issues in the Model Design

The fundamental purpose of the entire forecasting model system is to estimate the expected direct and indirect effects of any hypothesized horizon-year transportation plan. The estimation of indirect effects is handled entirely by the Econometric Model, while all four models are involved with forecasting the equilibrium pattern of loadings (and impedances) on network components. The basic function of the Network Simulation Model is to refine and/or summarize the information on traffic patterns produced by the Freight Modal Split and Passenger Demand Models. This section is primarily concerned with the extent of such refinement required for a satisfactory characterization of direct effects by each mode.

Just as traffic assignment techniques purport to estimate expected route patterns of automobile traffic, at first blush the Network Simulation Model for the Commonwealth might be construed as a tool for estimating the routing patterns of all traffic over a multimodal network. However, several factors suggest strongly that a thorough analysis of route choice be limited only to those modes of transport using the highway system.

The most important of these factors is feasibility. Throughout this report we have emphasized repeatedly the need to compare informative value against resource requirements in model design. Ideally, we would juxtapose with a highway assignment model a comprehensive, microscopic common carrier model which generates probable routings and schedules. Several models of this general nature exist, but represent massive implementation efforts, particularly if some of their more restrictive assumptions are relaxed. Furthermore, these models are based on the notion that a given carrier will optimize its operations in terms of profits or costs, and tend to overestimate performance efficiency.* The nature of the common carrier problem is of such complexity that no cost-

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* It can be argued that a common carrier model for PennDOT should be based on a rigid criterion of minimizing social costs, but regulatory authority is far more limited than would be necessary to implement the model's results. The previously footnoted RFP of the U.S. Department of Transportation suggests such an approach, which is somewhat more acceptable considering the concentration of common carrier regulatory authority at the Federal level. PennDOT should maintain an awareness of that research effort as it proceeds, and be prepared to cooperate with its regulatory policy implications.

effective compromise appears to fall between such a complicated approach and a very crude technique (such as an all-or-nothing minimum-path assignment).

An additional consideration of feasibility regards the use of a time-structured approach, such as that being developed for the Northeast Corridor Transportation Project. Throughout the report we have emphasized our decision to avoid major survey work for passenger travel, since substantial data are currently available (see chapters V and VI). A time-structured approach would require a survey of the temporal variations in passenger trip origins at each of 149 zones in order to take advantage of the time-dependent modeling concept. We have rejected such an approach strictly because of our limited-survey policy.

The second factor is a conceptual one: an analysis of route choice patterns is only meaningful for those modes which involve a complex network. For simple networks the concept of alternative routes is not pertinent; the determination of mode split for any given origin-destination pair may dictate one and only one route. Network simulation, as defined above, has no application in such cases. The waterways network in the Commonwealth is an obvious example.

The complexity of any network for any given mode, and the significance of a route choice analysis, of course heighten as larger and larger geographic areas and longer average trip lengths or hauls are considered. Current research at the Transportation Research Institute, for example, indicates that correlations of rail freight routing patterns with

objective route characteristics are not significant unless a transcontinental scope is considered. Thus, with even a relatively crude rail assignment model the patterns of rail freight routings within the Commonwealth cannot be predicted with appreciable confidence. Only that traffic which is of a relatively long average haul is susceptible to quantitative analysis, and then would require a model whose scope extends, for example, from the eastern seaboard to the Chicago and St. Louis gateways. A similar argument applies to commercial airline and pipeline transportation. Rather than fumble with a clumsy and pretentious quantitative model, then, we suggest that PennDOT look to the Federal government for analytically-based guidance in these situations. From all indications, mounting pressures are bearing upon the U.S. Department of Transportation and the Interstate Commerce Commission to develop evaluative network simulation models for the respective common carriers under their jurisdiction. We can only encourage PennDOT to increase this pressure further (a much simpler alternative than coordinating planning efforts with, say, ten other states).

The above remarks dictate that PennDOT's simulation in the sense of a "route allocation" function be restricted to modes which use the highway network for "line-haul" purposes. A remaining issue regards the extent to which the Network Simulation Model must act as a "list-processor" of modal split information and whether the notion of capacity restraint is relevant to any modes.

Like traffic assignment, the practical purpose of a network simulation (i.e., in terms of its utility to the planning effort) is to identify expected loadings on specific components of the abstract network to the extent that prior models fail to do so. This identification of component loadings affects the planning process in three distinct ways, depending upon the degree of utilization estimated for each component.

If some particular component which is proposed as part of a future transportation system is estimated to be seriously underutilized, this observation signals the planner(s) to cut back on the capacity originally hypothesized for that component, since a definite opportunity cost is associated with excess capacity. Thus, a proposed highway link may be cut back from six lanes to four (holding level of service constant), or a proposed airport (or air "node") may be revised to accommodate fewer landings per day. A key point here is that the identification of underutilized components is relevant only if such components represent improvements to the existing network. It is generally impractical to go out into the field and shave lanes from existing highways or to pull up existing trackage just because these facilities might not occasion heavy traffic.

The identification of component loadings also affects the planning process in cases of estimated overutilization. Whether a component of the abstract network represents existing or proposed facilities, if its assigned flow exceeds

its capacity then one of two strategies must be pursued. On the one hand, the planner(s) simply may delegate more capacity to the component. On the other hand, the forecasting model system may be designed to reallocate some of that traffic to nearby components (be they terminals, links or modes). The reallocation of traffic among facilities of the same mode should be accomplished by the Network Simulation Model. A reallocation to alternative modes calls for a feedback to one or both of the two prior models. In other words, on the one hand supply may be adjusted, and on the other hand the adjustments of demand may be traced. The latter dictates specific analytical operations within the forecasting model system.

The third case refers to situations in which assigned traffic does not exceed a component's capacity, but is high enough to suggest congestion. This circumstance refers specifically to highway links per the capacity restraint feature of a traffic assignment model (see section B above), but is applicable to any flow situation in which individual "free-agent" users compete for the same facility without any coordinative control (conceivably, queueing at airline counters could fall into this category if such detail were desired). This circumstance also calls for an iterative mechanism within the Network Simulation Model, at least for modes using the highway network.

To summarize the last four paragraphs, the need to cumulate the outputs of the two prior models (origin-destination flows by mode) for individual network components exists for

any given mode only if either of two conditions holds. First, if the anticipated demands upon that mode are great enough to suggest near-capacity utilization rates on the mode's network components, the origin-destination flows of the mode must be cumulated for its nodes and/or links with an allowance for feedback. Second, even if such high demands are not anticipated, any mode for which new components are proposed in a hypothesized plan requires a similar summarization of forecasted origin-destination flows. In this case, no feedback is necessary; the sole purpose of this summarization is to allow the planner(s) to strip excess capacity from these proposals.

Now let us synthesize this collage of observations in terms of their implications to the character of the Network Simulation Model. Early in the section we established that the model would perform a route allocation function only for modes using the highway network. This decision was prompted both by feasibility considerations and by the observation that non-highway common carrier routings can be analyzed effectively only at a much larger areal perspective than the Commonwealth. In line with this conclusion, we also asserted that a traditional traffic assignment approach, without the time-structure concept, shall be adapted for analyzing the highway network.

The second major issue introduced above regards the extent to which the outputs of the two prior models require summarization by node and/or link of any non-highway mode. This issue leads directly to the question of whether a

Statewide network need be defined and coded for any of these other modes. This task can be quite a tedious one, and is justifiable only if it proves to be more than marginally informative.

Our position is that only the State's highway system need be defined in terms of "links" in an abstract network. The modal split estimates of the two prior models shall be summed for each node (for either the passenger or freight zone system) to determine total originations and terminations for each non-highway mode, and manual comparisons against aggregate terminal capacities can be made on this basis. We assume that current rail technology will not draw sufficient traffic over the forecast period to approach route capacities, thereby eliminating the need to code rail links. Essentially, then, to the extent capacity considerations call for any feedback mechanisms in the model, we assume they will be prompted by either highway links or air (and conceivably rail) terminals or nodes. Should specific corridors for any mode (particularly a new mode such as the Keystone Corridor) require a capacity check for unforeseen reasons, it is a quite straightforward matter to sum manually all O-D flows as estimated by the two prior models. These points call for very minor refinements in methodology, and do not require elaboration here.

One final point to be made here regards the role of the Network Simulation Model in providing information on network characteristics for the Freight Modal Split and Passenger Demand Models. Both of those models require as inputs the

average rate or fare, the average total elapsed time, and the average frequencies for each mode (for every O-D pair). As a general rule, the tree-tracing (minimum path algorithm) feature of the Network Simulation Model would be applied to a given multimodal network in order to determine representative O-D costs and/or times where such measures are not obvious due to network complexity. Again, because only the highway system is indeed of such complexity, the tree-tracing feature will be used to determine first estimates of travel times for highway-oriented modes. Such measures for all non-highway modes shall be prepared exogenously by the planner(s). During the course of operating the entire forecasting model system, of course, this tree-tracing feature will be applied again to the highway network and average travel times revised directly by the computational algorithm (the capacity restraint feature); these revised travel times will then be fed back to the two prior models as part of the iterative solution process.* However, only highway travel times shall be so revised; rates or fares, times for non-highway modes, and service frequencies will remain constant for any given "run" of the forecasting model system. Capacities of air and/or rail nodes may be increased (or decreased) as discussed earlier, but this less probable operation shall be accomplished manually.

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* Chapter X elaborates on the coordinated operation of the entire model system.

## 2. The Abstract Network

The Network Simulation Model consists of a battery of analytical operations, the application of which depicts the manner in which given origin-destination flows utilize any hypothesized network. All of these operations involve a processing of an abstract representation of the physical transportation system which must be defined, coded and stored in a computer. The Network Simulation Model draws heavily upon the Bureau of Public Roads' traffic assignment model discussed earlier, and the questions of coding and computer storage are treated quite thoroughly in the Traffic Assignment Manual previously cited. The purpose of this section is to set forth basic guidelines for defining that abstract network.

The concepts of an abstract network, nodes, links and a "network description" were discussed at length in chapter II, and will be given very brief review here. A given study area is typically divided into an exhaustive set of zones; a centroid is located for each zone, and all traffic flowing out of or into each zone is assumed to originate or terminate at that centroid. Such a centroid is called a "loading node," and the travel of interest in the study occurs between these nodes. The loading nodes for the Network Simulation Model shall be identical to those used in the Edwards and Kelcey study, and will depict the generation of all interzonal traffic which uses the highway system in any manner.

In many studies (particularly those in urban areas), an additional set of "nonloading nodes" has been defined to

characterize significant decision-points in the route choice process, although they are assumed to represent no traffic generation. Such points at the State level include major interchanges, such as between expressways and major arterials, and possibly points of intermodal transfer. Again in accordance with the Edwards and Kelcey study, and reflecting our convictions regarding the proper character of a "master plan" (see chapter V), we recommend that no nonloading nodes be defined in the Statewide abstract network. All routing decision-points are adequately represented by the centroids of the 149 passenger traffic zones in the Commonwealth (and the 14 peripheral zones).*

The definition of the abstract network is completed by connecting the zone centroids by abstract "links," which constitute aggregated representations of major highway facilities. The basic link system shall be identical to that defined by the Edwards and Kelcey study. Any sequence of these links comprises a highway route, and therefore all highway routes pass through zone centroids.** Each link shall be characterized by its length and by a capacity function, as specified by a particular mathematical form and

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* Recalling that the results of the Freight Modal Split Model are quoted in terms of the coarser freight traffic zones (on the order of 30), it should be pointed out that the origin-destination flows for any freight mode involving the highway network must be factored down to a passenger zone basis. Some index such as the distribution of truck terminals, controlled by observed commercial vehicle percentages, might be used for this prorating.

**This point calls for slight modification of the BPR tree-tracing program (see the Traffic Assignment Manual).

two parameters representing maximum possible flow and mean free speed. Alternative mathematical forms are discussed in Appendix IX-A, and may be evaluated by limited experimentation. To take full advantage of Overgaard's research (discussed in section B above), we recommend that his form of capacity function be used unless experimentation should perchance prove it a weaker descriptor than the others.

As discussed in the previous subsection, no abstract network (in the sense of internodal links) shall be defined for non-highway modes. If desired, however, the terminal activities of such modes may be represented by considering the centroid of every passenger (or freight) zone to depict either individual terminals or aggregations of terminals. For example, the Greater Pittsburgh Airport lies within zone #031 of the Edwards and Kelcey zone system; that airport facility shall be represented by the zone's centroid as defined per the previous paragraph. As another example, suppose one of the freight zones were to include Cambria and Blair counties. The centroid of that freight zone would then be used to represent the combined facilities of the Morrellville classification yard in the Johnstown vicinity and the Altoona classification yard. Note, of course, that the definition of nodes for the freight zones does not suggest that internodal links be defined for that zone system. The only motive for assigning non-highway terminal activities to such centroids is for convenience in accounting. As is discussed in the following subsection, the design provides an option

for summarizing any non-highway mode's O-D flows at such nodes, in the event that a comparison to nodal capacities is desired.

## 3. Analytical Operations

As regards the design of the Network Simulation Model in analytical terms, it basically involves a few modifications of the BPR traffic assignment package which was given thorough review in section B and for which very detailed documentation exists (the Traffic Assignment Manual previously cited). Accordingly, we refrain from presenting detail here which is redundant to those descriptions. Rather, this subsection is more concerned with defining several peripheral operations as well as the necessary modifications of the BPR model. The peripheral operations, as they relate to the highway assignment model, are depicted in Figure XI-4. Each of these operations is discussed under a separate subheading below.

### a. Vehicle Conversions

The first step required in the operation of the model is the conversion of the passenger flows and tonnage flows, as given by the two prior models for each mode, into vehicle units. These units are more appropriate for network simulation since capacity measures and highway link capacity functions are more meaningfully expressed in terms of the entities which flow over a facility. These conversions will be developed from available load factor information and supplementary data (see section B.2 of chapter X).

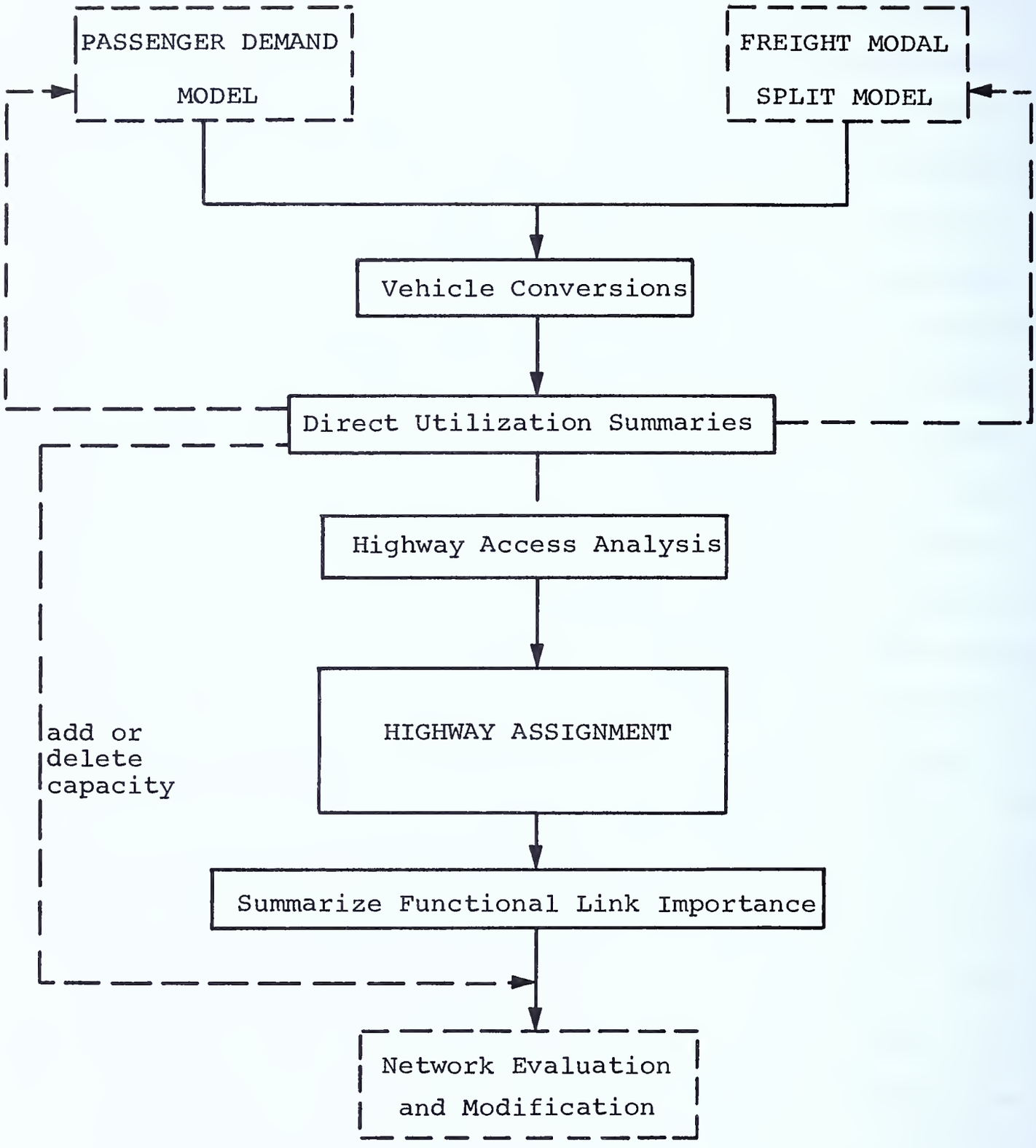


Figure IX-4. Analytical Operations of the Network Simulation Model

b. Direct Utilization Summaries

While only those modes using the highway system are to be analyzed in a network context, this second operation in the model provides for comparing estimated flows to available capacities for components of non-highway modes. The operation may be performed either automatically or manually, since all that is involved is a summarization of origin-destination flows for any given mode to determine a first-order approximation of terminal (node) flows. The summarization shall be accomplished for total originating traffic and total terminating traffic by cumulating the O-D flows over all destination nodes and origin nodes respectively, and applying appropriate factors indicative of the probable proportion of interchange or transfer traffic to total traffic, where necessary. This comparison of flows to capacities may suggest either an increase or decrease in the capacity of a mode at any given node, or it conceivably might dictate a feedback to the Freight Modal Split and/or Passenger Demand Models to reallocate surplus demand to another mode. A similar approach can be handled manually for links as the planning staff sees fit.

c. Highway Access Analysis

The purpose of this operation is to separate out all interzonal highway travel which represents an access portion of a predominantly non-highway movement. Examples are auto travel to and from airports, and perhaps the over-the-highway portion of piggyback movements. A preliminary operation is

required which uses the BPR tree-trace algorithm to delineate terminal market and supply areas for each mode to be considered in this step. This task is particularly relevant to air passenger movements, since it is not necessarily obvious from inspection which of several airports will be used by potential air passengers in a given zone. This application of the minimum-path algorithm will assume free travel times.

Given this definition of market areas for airports and other terminal facilities of interest, the O-D flows received from the Freight Modal Split and Passenger Demand Models are to be transformed into truck or auto O-D flows which constitute the access portions of these flows. These interzonal flows by highway shall then be added to the O-D flows estimated by the two prior models for modes using the highway system.

### d. Highway Assignment

The highway assignment operation, which involves a somewhat complicated adaptation of the BPR traffic assignment model, is the core of the Network Simulation Model. The three distinct modes of auto, truck and bus are assigned separately, although the route choice patterns of the latter two modes depend upon the route patterns determined for the auto mode. This dependence is effectuated through the use of a capacity-restrained option of the BPR package for automobile traffic.

Specifically, the capacity-restrained all-or-nothing algorithm discussed in section B is to be used to assign automobile traffic to the highway network. As described by Humphrey* (which should be studied in parallel with the Manual), this algorithm performs a sequential generation of routes so that traffic can be allocated to several paths for each O-D pair in accordance with equation (IX-6). Link capacity functions which express travel time (or cost) as a function link volume are used to revise link impedance values within an iterative route generation and allocation process. Automobile traffic shall be assigned on the basis of route travel times; therefore the tree-tracing operation will be performed in terms of a minimum-time criterion. Given the several routes generated for each O-D pair by this procedure, truck flows and bus flows are then assigned to the best of such paths (no additional route generation is required). The notion of "best" may refer either to time or cost; limited research will dictate which measure provides the most accurate results. Should the assignment of truck and bus flows affect link (and therefore route) travel times significantly, an outer iteration loop may be required.

### e. Summary of Functional Link Performance

For the benefit of the task of fashioning alternative networks, which is accomplished within the framework of a functional highway classification analysis (see section C of chapter X), some auxiliary computations are required to

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* Humphrey, T. F., op. cit.

summarize the functional performance of each link in the highway network. Specifically, for each link the average trip length and the percentage of commercial vehicles of the traffic using that link (per the highway assignment) must be summarized. This operation requires that origin-destination characteristics of assigned traffic must be retained in memory as that traffic is allocated to the highway links.

# APPENDIX IX-A
# HIGHWAY LINK CAPACITY FUNCTIONS

This appendix briefly discusses and illustrates several link capacity restraint functions used or proposed for use in highway assignment. The general form for the impedance function is:

$$\omega = f(q) \qquad \text{(IX-A-1)}$$

where $\omega$ is the impedance expressed as a cost/unit flow or time/unit flow and q is the flow rate (vehicles/time unit). The notation used is uniform throughout and is as follows:

$\bar{\omega}$ = the impedance when traversing the link at mean free speed

C = the capacity; the maximum flow rate possible on the link

$\omega_c$ = the impedance at capacity

The BPR Assignment package* uses the following function:

$$\omega = \omega \left[ 1 + 0.15 \ (q/C)^4 \right] \qquad \text{(IX-A-2)}$$

This is illustrated in Figure IX-A-1. At capacity the impedance is 1.15 times its value at mean free speed. The function allows flow beyond capacity.

Overgaard, in his work,** uses the following function:

$$\omega = \bar{\omega} \cdot a^{(q/C)^b} \qquad \text{(IX-A-3)}$$

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* Bureau of Public Roads, op. cit.

**Overgaard, H. R., op. cit.

In this function, a and b are parameters for the particular type of road. Figure IX-A-2 illustrates this curve with a = 1.40 and b = 3.0. This function, like the BPR form, allows flow beyond capacity. One important feature of this function is the flexibility it allows in the choice of the parameters a and b to fit the particular types of highways being studied. The range of values suggested for a are 1.15 and 1.7.

Mosher* suggests as candidates for link capacity functions the hyperbolic and logarithmic forms. He points out that the characteristics of these functions are such that the change in "impedance per unit of flow" as flow increases is small for low flow values, but large as saturation flow is approached. For both functions the impedance approaches infinity as capacity is approached.

The logarithmic form is:

$$\omega = \log C - \log(C-q) + \bar{\omega} \qquad \text{(IX-A-4)}$$

This function is illustrated in Figure IX-A-3.

The hyperbolic function is:

$$\omega = \omega_A - \frac{C(\bar{\omega} - \omega_A)}{q-C} \quad \text{and} \quad \omega_A < \bar{\omega} \qquad \text{(IX-A-5)}$$

where $\omega_A$ is the horizontal impedance asymptote of the function. The function is illustrated in Figure IX-A-4. The flexible feature of this form is the $\omega_A$ asymptote. This controls the flatness of the function at low values of flow.

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* Mosher, W. W., Jr., op. cit.

Any of the capacity restraint functions discussed above can be implemented in the network assignment algorithm for highways. The choice must be dictated by data on traffic flow on various types of links.

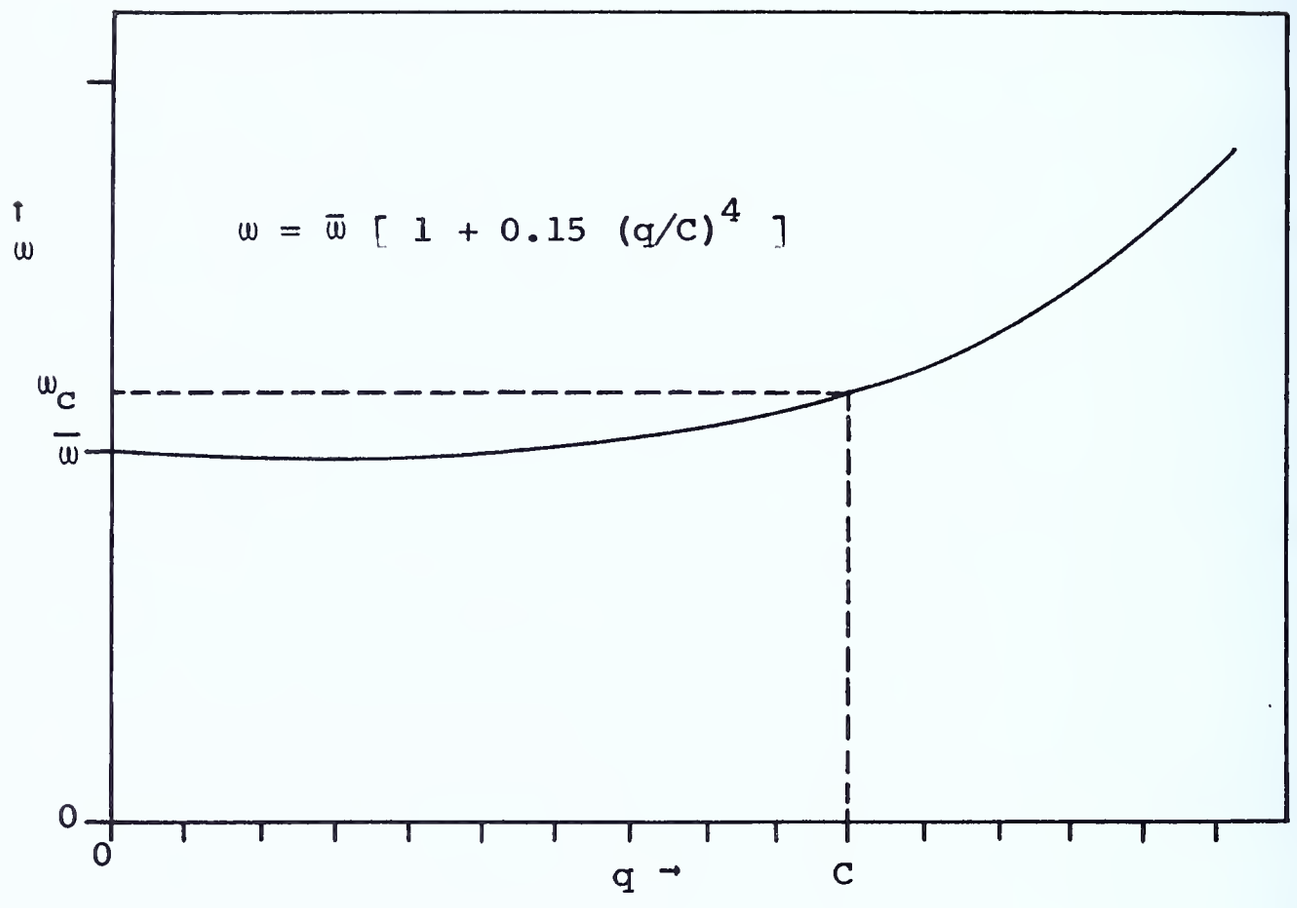


Figure IX-A-1. The Bureau of Public Roads Capacity Function

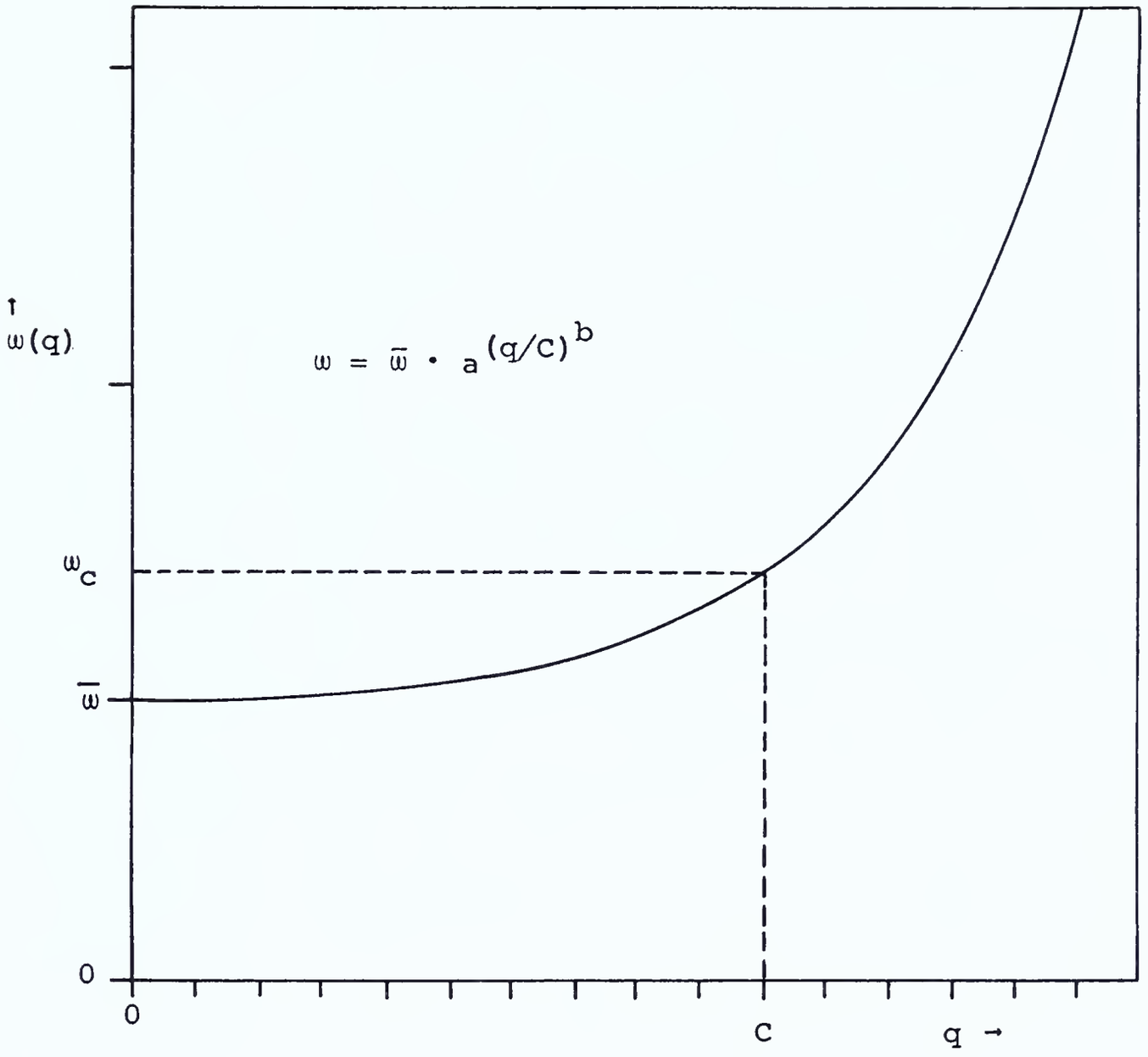


Figure IX-A-2. The Overgaard Capacity Function

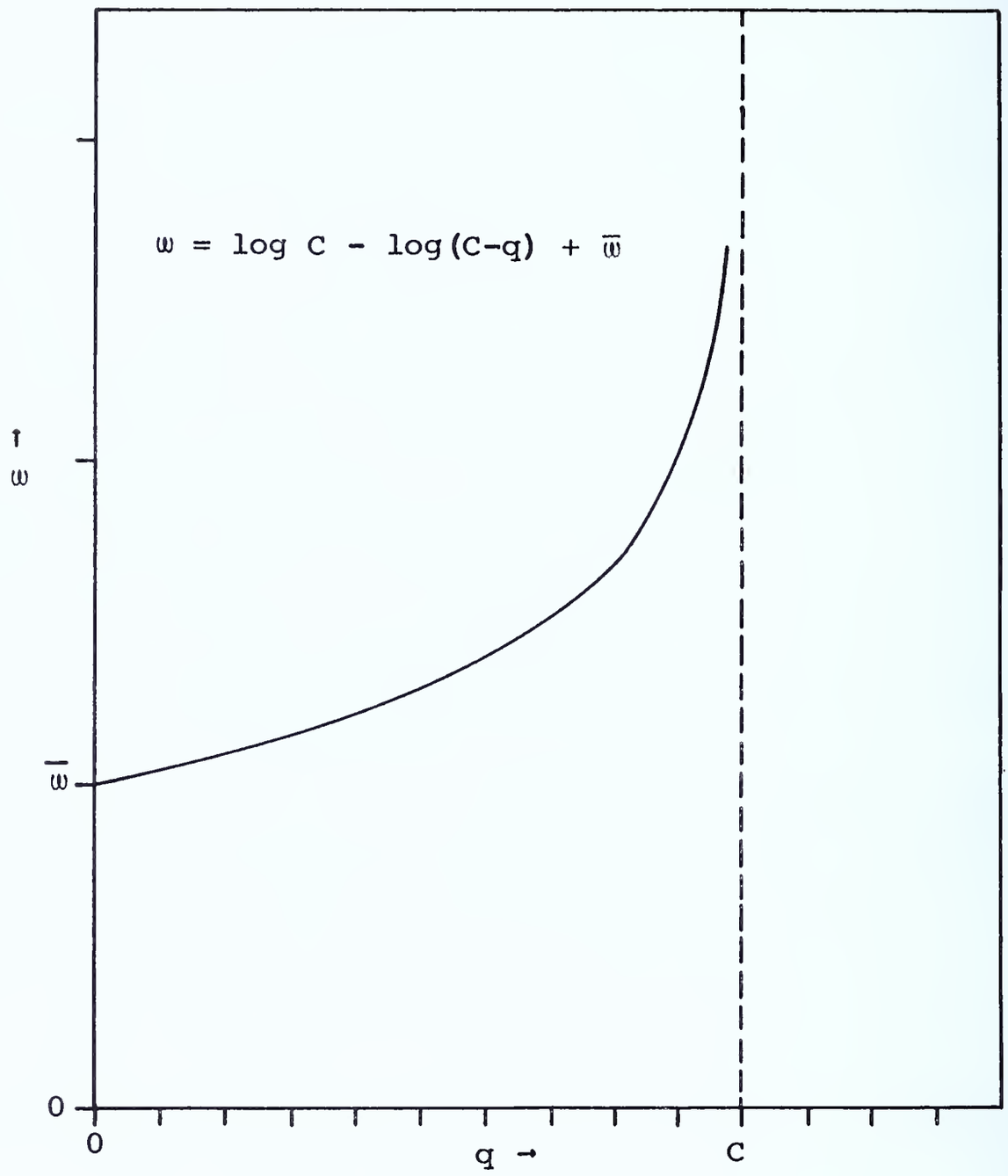


Figure IX-A-3. The Logarithmic Capacity Function

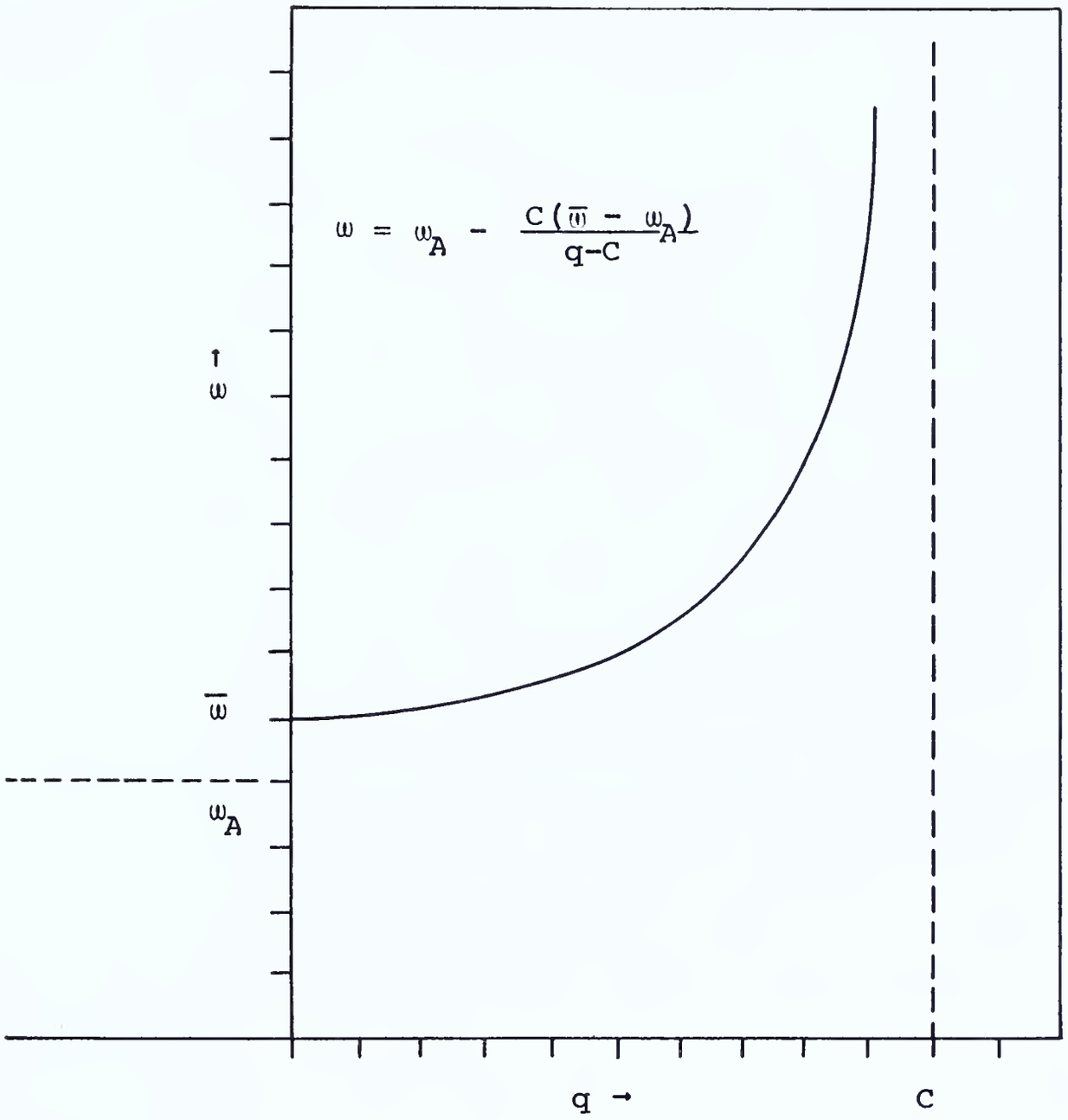


Figure IX-A-4. The Hyperbolic Capacity Function

# X
# THE INTEGRATED TRANSPORTATION PLANNING PROCESS

## A. Introduction

The previous three chapters have discussed in detail the four major components of the forecasting model system, with emphasis being placed on the internal characteristics of each model. Except in very general terms, the manner in which these models must interface with each other was not discussed. Furthermore, the ultimate use of the models to fashion and evaluate alternative transportation plans was virtually ignored, save for the introductory perspective provided in chapter VI. The purpose of this chapter is to explore these two themes in detail, thereby integrating all prior material.

Throughout both of its Parts, this report has been structured in terms of the seven-task characterization of the transportation planning process as defined in chapters II and VI. The first three steps in that characterization, which address the identification of relevant policy and effect variables and associated data requirements, were discussed definitively in chapter VI. Chapters VII through IX have addressed the major elements of the fourth step, the design and calibration of the individual models in the forecasting model system. In the next section of this chapter we complete the articulation of that fourth step by concentrating on the coordination of those individual models into an integrated forecasting tool. The latter part of the

chapter focuses upon the last three steps in the task characterization, whereby alternative plans are hypothesized, evaluated and refashioned by applying the integrated forecasting model system.

Before proceeding to these matters, we wish to underscore the fact that while the distinction is convenient for communication purposes, the forecasting model system and the tasks of fashioning and evaluating alternative plans are inseparable. Chapters VII through IX were addressed to the task of developing a forecasting model system; this chapter is concerned with the application of that model system as portrayed in Figure VI-2. The logic of the chapter is simply that in order to appreciate the application of the model system to the formulation of alternative plans, the model system in its entirety must first be defined. Of necessity, the coordination of the model system (see section B) must be discussed in the context of the total planning process, including network formulation and evaluation. However, a detailed discussion of these broader elements is reserved for section C. Section D summarizes this very important chapter.

## B. Model System Coordination

The purpose of this section is to present the integrated system of models, showing how they operate together to form a transport-sensitive assessment of expected direct and indirect effects. It would be misleading to imply that all parts of the forecasting model system fit together as an

electric plug fits into a wall socket. There are some conversions that must be applied to the information as it flows from one part of the model system to the next. Each model must receive its input information in a specific form, which must be compatible with the outputs of the models which estimate such information. There are also several interfaces where simple conversion is not enough, where the PennDOT planning staff will be required to make judgments. Without this interaction and integration, the dynamic and policy-sensitive character of the forecasting model system is lost.

To aid in this discussion of model system coordination, the entire planning process is conveniently divided into five parts. The first part is the Econometric Model, which predicts the distribution of goods in the study area as well as the distribution of population and economic activity. The second includes the Freight Modal Split Model, which predicts the amount of freight that will flow by each mode, and the Passenger Demand Model, which predicts the passenger traffic by mode throughout the study region. The third part is the Network Simulation Model, which allocates flows of people and goods, by modes, to the links of the transportation network. The fourth is the task of network system evaluation, which examines the predicted traffic flows on each link and evaluates a proposed network according to the performance efficiency and the continuity of the proposed link arrangement.

The fifth part is the procedure of fashioning alternative transportation systems.*

The following two subsections will examine the forecasting model system, first with regard to its dynamic features, and then with regard to the form of information that is to flow between the models. In other words, the first subsection gives a generalized discussion of the information flow, emphasizing the dynamic character of the model system, while the second subsection details the interfaces between individual components and points out anticipated coordination problems.

## 1. Dynamic Operation of the Model System

The flow diagram shown in Figure X-1 will form the basis of this discussion of dynamic operation. The boxes in that figure represent operations to be carried out by the individual models, and the items in parentheses represent information flow.

The Econometric Model requires socioeconomic data for some base year for the entire study area, as well as for all external nodes considered. Transportation system variables are included in the form of estimated costs of freight transportation between each origin-destination (O-D) pair. This information is operated upon to provide a prediction of the distribution of population and economic activity

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* We place the task of fashioning alternatives last here to emphasize its role of formulating <u>future</u> systems. The first run of the model system will assume no modification of the existing network.

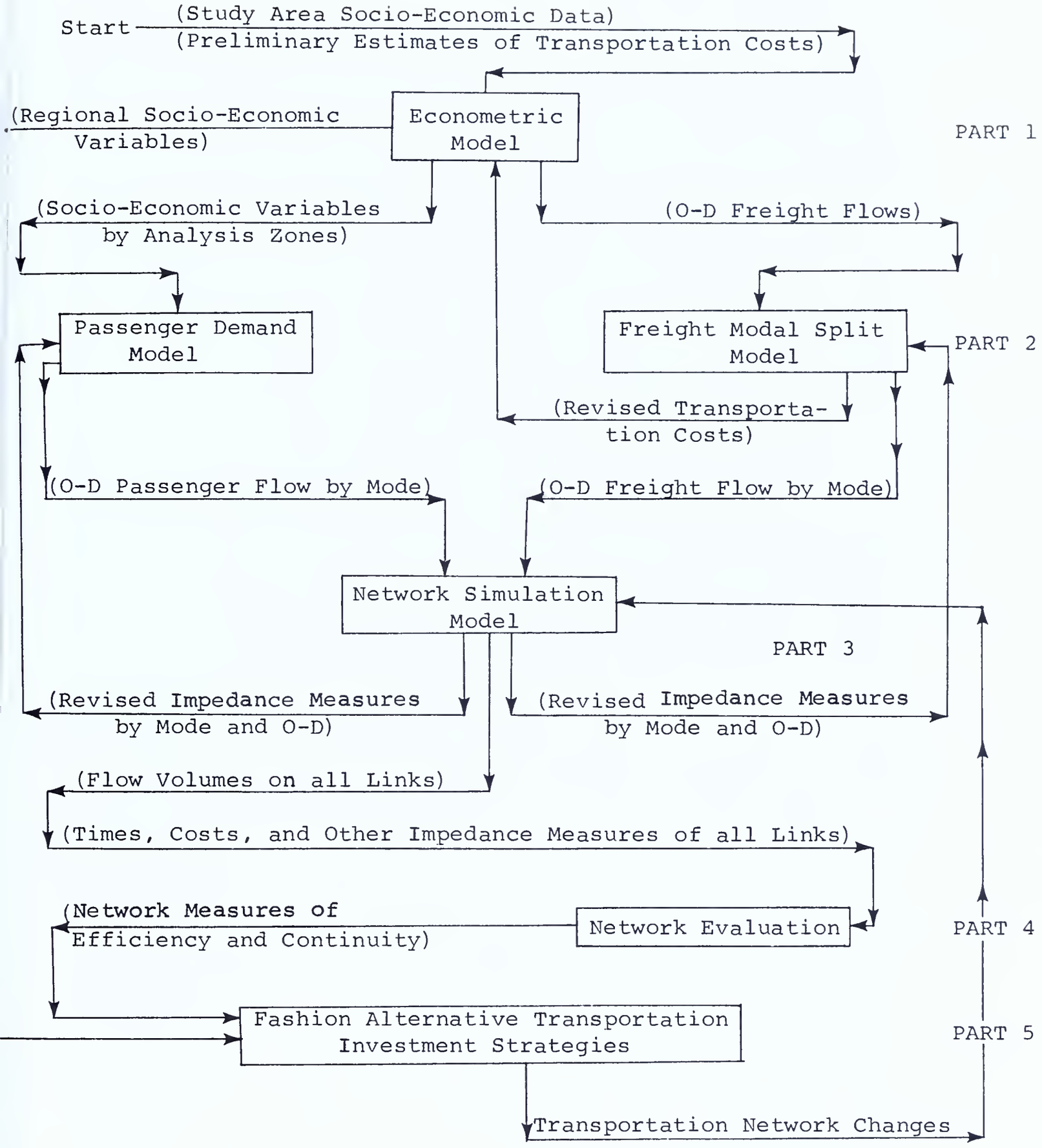



Figure X-1. Generalized Model System Flow Chart

among the analysis zones (or nodes) and the flow of commodities between these zones.

The freight flow predictions are used as part of the input for the Freight Modal Split Model. Here, the transportation system characteristics required are the cost, time and relative convenience of each mode being considered. The values of the time (and in some cases, cost) variables used at this point are preliminary, pending the loading of the transportation network by the Network Simulation Model (see below). Freight flows by modes for each O-D pair are predicted on the basis of these estimates.

The Passenger Demand Model uses the same types of network characteristics as the Freight Modal Split Model. However, the information received from the Econometric Model is the estimated distribution of socioeconomic activity for each of the analysis zones. The output of this part of the system is a prediction of the movements of passengers between the nodes in the study area by mode. Again, the values of cost and/or time variables are preliminary estimates.

The function of the Network Simulation Model is to allocate the flows of passengers and goods to the individual components of the transportation network. The outputs of the model include the volumes of traffic flow for the various components and revised values of network characteristics, to the extent that they are affected by loading.

In general, the time and cost of travel on the network (at least for modes using the highway system) must be

calculated based on the predicted flows for each mode and link, since heavy loadings suggest congestion. These revised estimates of travel time and cost are fed back to the Freight Modal Split and Passenger Demand Models, which use these measures as explanatory variables. The revised flows by mode, which are then estimated by these two models, are input once again to the Network Simulation Model to produce another estimate of network characteristics. This iterative process is continued until the changes in traffic volumes and/or impedances (travel time or cost) are small. The equilibrium values of the network parameters are then utilized by the Freight Modal Split Model to obtain a revised estimate of the cost of freight transportation services (an example calculation is given in the next subsection). If this cost differs significantly from the last estimate used in the Econometric Model, the entire process is repeated.

When the results provided by the first three parts are satisfactory (i.e., when some convergence criterion is met), the information on equilibrium flows and costs is then given evaluative scrutiny (part 4 in Figure X-1). This step examines the performance efficiency of the hypothesized network and identifies weak components and network discontinuities.

The next procedure is the fashioning of alternative transportation networks. At this point, the planning staff must examine the results of the network evaluation step and suggest appropriate modifications to the last network

tested. As will be explained in section C below, an iterative cycle is also pursued between this step and the Network Simulation Model (or conceivably the two prior models). The modifications to the last network effectuate revisions in network characteristics, and the reaction of the flow patterns to these changes must be traced and again evaluated. To an appreciable extent, the task of fashioning alternative networks is sensitive to Statewide development policy, whereby alternative weightings of the Commonwealth's geographic areas are taken as overall constraints and a satisfactory network is evolved through the iterative mechanism just described. Eventually, the "best" or "most satisfactory" (as opposed to "optimal") networks for each alternative development policy are presented to decision-makers, along with a summary of direct and indirect effects (and capital costs) for each.

Several items deserve re-emphasis before proceeding to a more detailed examination of the model system coordination. Notice that in each part of the forecasting model system, predictions are a function of transportation characteristics. The Econometric Model predicts the distribution of population and economic activity (including freight flows) based, in part, on the costs of transporting goods. The Freight Modal Split Model uses the travel time, cost and convenience of the individual freight modes to predict the volume of goods that will use each mode. The Passenger Demand Model uses the costs, times and convenience of the passenger modes to estimate the division of passenger traffic by mode. The

Network Simulation Model allocates traffic to the highway network's various routes on the basis of those routes' times (or costs). It also adjusts times (and costs, if desired) to reflect high utilizations of network components, leading to the iterative process described above. The transport-sensitivity and dynamic features of the forecasting model system are achieved because each iteration of the process provides more accurate estimates of the realized network characteristics and traffic flows.

One additional point of considerable relevance is the role of chronological time in the operation of the forecasting model system. As discussed in chapter V, this methodology is directed toward long-range planning, and the model system is intended to be so operated. While we defer from recommending a specific horizon-year (or a specific Statewide population total in lieu of a specific year), the period of time between the base- and horizon-years is assumed to be on the order of twenty years. The lower components in Figure X-1 may be applied legitimately for shorter periods; the Network Simulation Model may be applied on a yearly basis, and the two prior models on perhaps a five-year basis. Conceivably the Econometric Model can be operated to predict over a ten-year period or less, assuming that lags between the response of industrial activity to transportation change can be ignored. In any event, the model system is not designed to operate recursively in the sense of propagating itself through future time.

To summarize, this subsection has discussed the operation of the forecasting model system as a whole, by pointing out the iterative procedure that is vital to the dynamic transport-sensitivity of the system. The following subsection examines the interfaces between the individual models in greater detail to expose the implementation problems that exist at these junctures.

## 2. Model System Interfaces

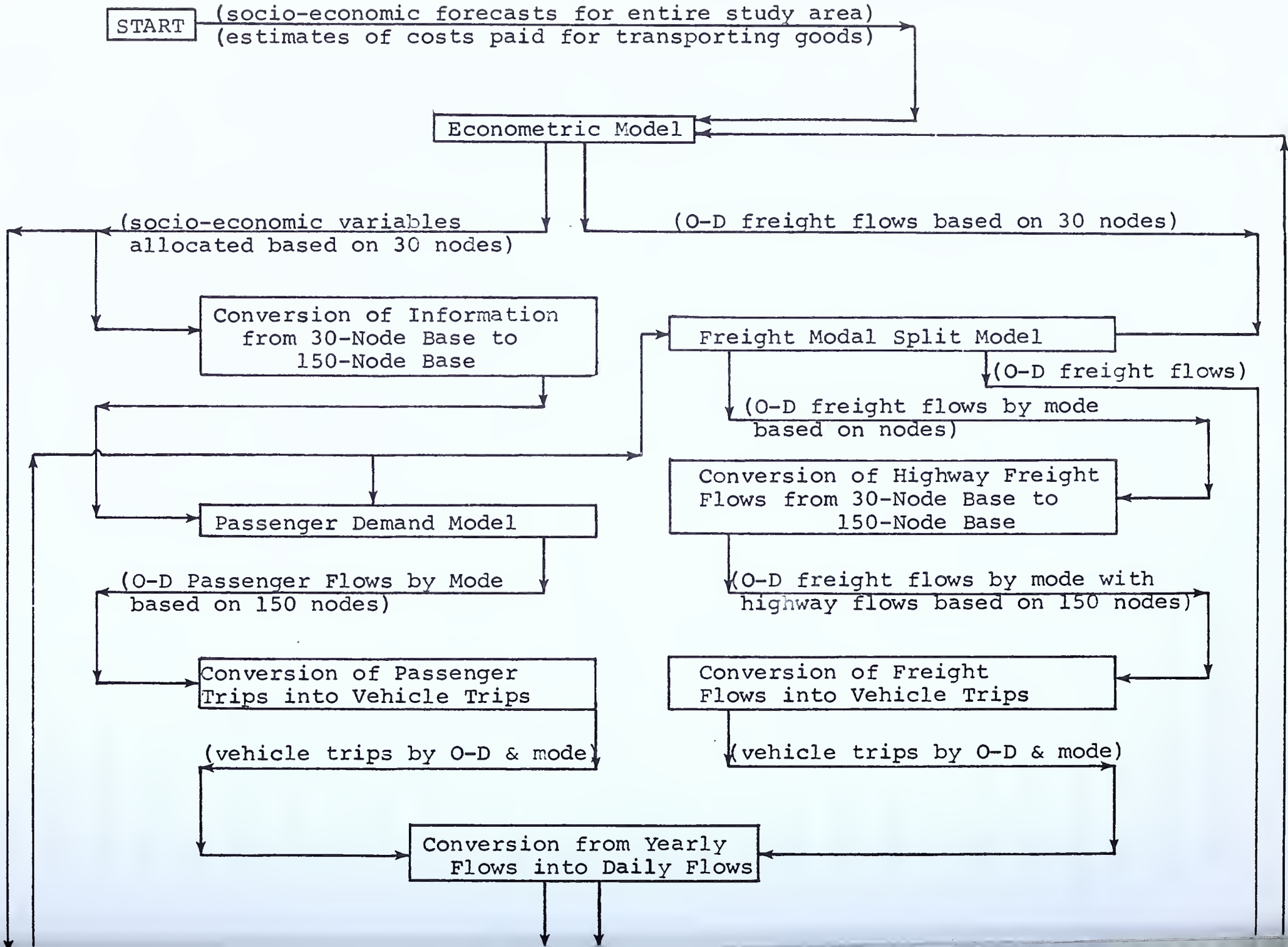
Between each part of the forecasting model system, an interface exists. Some of these interfaces are smooth, and information is passed directly from one model to another without any transformation. At other interfaces, the information must be operated upon to convert it into compatible form. This subsection examines these interfaces and points out where conversions must be made.

A detailed flow diagram depicting these interfaces is presented in Figure X-2. This diagram shows, in addition to the information shown in Figure X-1, the conversion procedures that must be applied to the information flowing between the individual parts of the model system. While this flow diagram appears to be very complex, it is presented in this form as a basic guide to the implementation of the methodology.

The first conversion required is that between the Econometric Model and the Passenger Demand Model. This is necessitated by the relatively large zone size employed in the Econometric Model. It is expected that, because of

practical considerations, the Econometric Model will consider Pennsylvania to be composed of about thirty regions. This would require larger aggregations of the highway network than would be desirable for planning purposes. It seems much more reasonable to provide for an analysis based on the 149 traffic zones used by the Edwards and Kelcey study, as discussed in chapter V. It is necessary, therefore, to develop a methodology for allocating the output for each freight zone from the Econometric Model to the smaller passenger traffic zones. As discussed in chapter VIII, the prorating strategy used by the Edwards and Kelcey study for its own socioeconomic projections is recommended for this allocation.

The next information conversion occurs between the Freight Modal Split Model and the Network Simulation Model. Again, to provide the detail necessary for the evaluation of the highway system, the flows by motor freight must be converted from the freight zone system to the passenger zone system. This task could be accomplished by referring to local land use data and allocating the flow volumes according to the distribution of industries and/or trucking terminals within the thirty-odd freight zones. Note that this process would allocate the flow between the larger zones to the smaller zone-pairs; however, it would not provide information about flows within the larger zones. The Econometric Model predicts both the total exportation of commodities from the larger zones and the internal consumption of each commodity


START
(socio-economic forecasts for entire study area)
(estimates of costs paid for transporting goods)
Econometric Model
(socio-economic variables allocated based on 30 nodes)
(O-D freight flows based on 30 nodes)
Conversion of Information from 30-Node Base to 150-Node Base
Freight Modal Split Model
(O-D freight flows)
(O-D freight flows by mode based on nodes)
Passenger Demand Model
Conversion of Highway Freight Flows from 30-Node Base to 150-Node Base
(O-D Passenger Flows by Mode based on 150 nodes)
(O-D freight flows by mode with highway flows based on 150 nodes)
Conversion of Passenger Trips into Vehicle Trips
Conversion of Freight Flows into Vehicle Trips
(vehicle trips by O-D & mode)
(vehicle trips by O-D & mode)
Conversion from Yearly Flows into Daily Flows

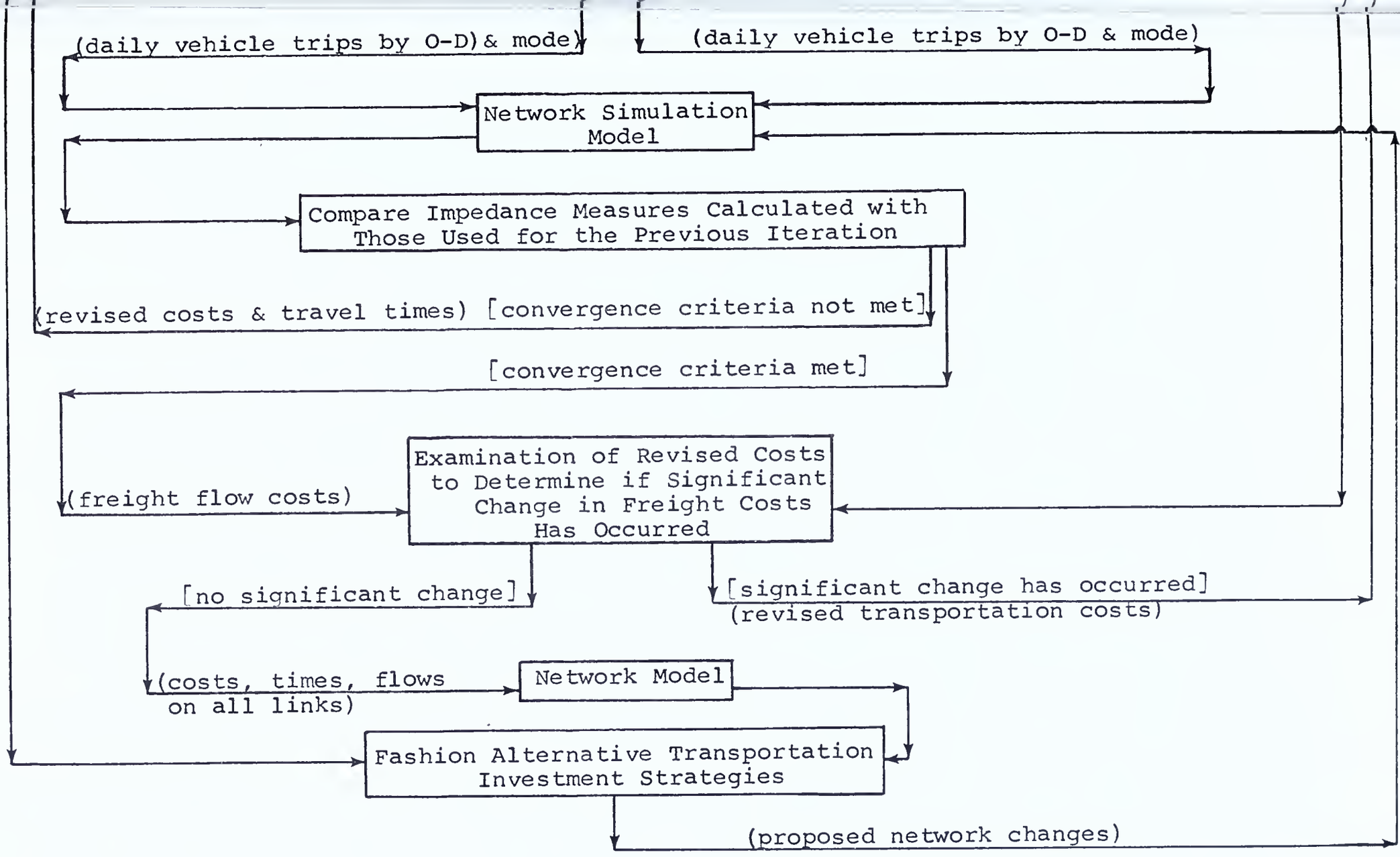

(daily vehicle trips by O-D)& mode)
(daily vehicle trips by O-D & mode)
Network Simulation Model
Compare Impedance Measures Calculated with Those Used for the Previous Iteration
(revised costs & travel times) [convergence criteria not met]
[convergence criteria met]
(freight flow costs)
Examination of Revised Costs to Determine if Significant Change in Freight Costs Has Occurred
[no significant change]
[significant change has occurred]
(revised transportation costs)
(costs, times, flows on all links)
Network Model
Fashion Alternative Transportation Investment Strategies
(proposed network changes)

Figure X-2. Detailed Model System Flow Chart

by each industry located within each of the larger zones. Again, by referring to the location of industries within the larger regions, and using the internal consumption predictions, the intrazonal movements could be delineated. The problem should not be a serious one, since the average haul of the motor carrier mode is considerably greater than the average distance between passenger zones.

Proceeding through the flow diagram, the next task to be accomplished is a conversion of both passenger trips and freight flows into vehicle trips. This transformation could be achieved by applying appropriate load factors to the flows. At present, load factors are well-defined for commercial air passenger travel and, possibly, for automobile travel. But for other passenger modes, and all freight modes, this information would have to be obtained. Loadometer data might provide a reasonable estimate of average load per truck, if the inconsistencies in that raw data could be ironed out.

To this point in the operation of the model system, all tasks have been performed on yearly data; that is, the passenger and freight flow predictions are in terms of traffic per year. While this level of temporal aggregation is desirable in the Econometric, Passenger Demand and Freight Modal Split Models, yearly flow (or average daily traffic -- ADT) is not sufficient to describe network capacity requirements. It is necessary to convert these measures into more meaningful flow figures before the Network Simulation Model begins its operations. In Pennsylvania, a wealth of

data and reliable procedures exist for converting ADT for highways into more useful flow volumes. Similar procedures are suggested to handle the problem for other modes. The converted traffic flows (which will be the ADT adjusted by some measure of the peaking conditions on Pennsylvania's transportation network) will become the input to the Network Simulation Model.

The next interface problem occurs in the feedback of information from the Network Simulation Model to the Freight Modal Split and Passenger Demand Models. Both of these models use estimates of the cost, time and convenience of travel on all modes to predict the flow volumes by mode. The function of the Network Simulation Model in this regard is to adjust the times and costs of highway links, at least, to reflect the congestion effect suggested by the flows assigned to those links. The travel times between O-D pairs, as summarized from the results of the Network Simulation Model in any given pass, become the revised estimates to be used directly in both the Passenger Demand and Freight Modal Split Models. The cost of travel by private means is also used directly by these models. However, the cost of travel by common carriers is the fare or rate charged by that carrier to those who wish to use the service. While this charge is usually related to the carrier's costs, which in turn are conceivably related to service times, changes in impedance caused by overloaded links or network changes may not be reflected in the fares or rates. The issue here is whether the rates used in the two prior models should be

revised by the Network Simulation Model. Pending further research, we recommend that fares and rates be held constant. Meanwhile, the Passenger Demand and Freight Modal Split Models are to be run again, providing revised estimates of flows based on the revised time and cost via private means.

When the interactions of the Network Simulation Model and the two prior models have produced a suitable solution, a comparison must be made between the transportation cost values used by the Econometric Model in the previous iteration and those implied by the Network Simulation Model by virtue of its feedback to the Freight Modal Split Model. This comparison must be accomplished by multiplying the freight flows on each mode by the rates charged for that service. If, for example, the flow of a particular commodity between two zones is 100 tons, and the Freight Modal Split Model shows 30 tons moving by highway and 70 tons moving by rail, the cost of moving that commodity per ton is 0.3 times the rate by highway plus 0.7 times the rail rate. If the costs thus calculated do not agree with the cost estimates used on the previous iteration, the new costs should be used as the inputs to the Econometric Model, and another iteration should be carried forth.

With revised cost estimates and the original socio-economic data, the entire model system as described above is run again. The iterations are continued until reasonable agreement between estimated and calculated costs is reached. At this point, the predictions from all parts of the

forecasting model system represent the expected direct and indirect effects associated with a given transportation network and the exogenously prepared population forecast (see chapter VI). From this point, the task of evaluating the proposed network and refining it or revising assumptions about State development policy are initiated. This broader "plan design" operation also involves an iterative mechanism with parts of the forecasting model system, as the following section clarifies.

Before going on to that broader methodological strategy, one last point should be mentioned. In several instances during the preceding discussion, reference was made to "convergence criteria" and "reasonable agreement." Purposely, no further comment was made. While it would be possible for us to present opinions as to what tolerances are appropriate in the iterative mechanism, these are really questions which are better answered by experience gained from operating the model system. This situation typifies the obvious role of the learning process on the part of PennDOT planning staff. A variety of decisions regarding the operation of the model system will depend directly on the experience of the staff in the planning profession and their prior experience with the model system. It cannot be overemphasized that the forecasting model system is a planning tool and that the value of its results is very much a function of the staff's general talents and their specific experience with this tool.

## C. The Formulation and Evaluation of Alternative Plans

The previous section, together with the material presented in chapters VII through IX, has set forth our total design of the forecasting model system for PennDOT's Statewide long-range planning activity. In terms of the seven-task characterization of the transportation planning process which permeates this entire report, then, we have completed our recommendations for the first four elements. From this juncture, we assume that such a model system has been implemented, including the estimation of each model's parameters and the perfection of the interfaces between those models. The remainder of this chapter is concerned with a strategy for using that forecasting model system to produce a Statewide long-range transportation master plan.

Thus, this discussion shall present our recommendations for the last three elements in the seven-step characterization:

(5) the generation of alternative transportation plans

(6) the application of the forecasting model system to estimate the relevant consequences of each alternative

(7) the selection of a "best" alternative by a comparative evaluation of each alternative's estimated consequences and capital costs.

The reader will recall from chapters II, V and VI that the "trial-and-retrial search" strategy inherent to this characterization, vis-a-vis the direct solution for one uniquely optimal transportation plan, is prompted by two critical constraints. First, the latter approach would require a well-defined set of goals which would have to be prespecified

for the planning effort, and to which the ultimate decision-makers would have to remain committed through the course of that effort. For reasons discussed earlier, this requirement is too academic for us to expect its implementation, given the very complex political mechanisms prevalent in state government.

The other constraining factor refers to the analytical expertise offered by the current state-of-the-art in transportation planning. Suppose that it were possible, indeed, to resolve all conflicts between all interested parties so as to reach a genuine, well articulated set of planning objectives accompanied by universal commitment. Unless the resulting goals formulation were extremely simple, which would be highly unlikely, the planning profession and its supporting operations research discipline would lack feasible analytical techniques for directly producing a uniquely optimal plan in accordance with those objectives. Like most complex design problems, then, an iterative "search and selection" strategy is required in order to derive a "best" transportation plan.* This strategy is embodied in the last three elements of the seven-step characterization as noted above.

## 1. The Interface Between Planning and Policy-Making

Throughout this report, we have referred to this sequence of seven operations as a characterization of the planning

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* The term "best" is applied loosely here. Technically, the nature of such a search process is that any one alternative can be deemed "better" only in reference to all alternatives generated and tested. Conceivably a more attractive alternative may exist but may never be generated for consideration.

process. Before elaborating upon our recommendations for the final three elements, we should clarify our position regarding just whom shall be responsible for task 7 -- the evaluation of alternative plans. A long-range Statewide transportation plan will be of tremendous importance to the Commonwealth. It follows that such a plan must be chosen ultimately by the Governor and the General Assembly, rather than by the planning staff of PennDOT. In the sense that task 7 represents such an ultimate evaluation, it thereby refers to said policy-makers. It must also be noted, however, that in the process of generating candidate plans for perusal by these policy-makers, the planning effort itself also involves a comparative evaluation of alternatives. This planning activity, which functions to eliminate a variety of plans which are obviously inferior, will be treated here as part of task 5. The key point to bear in mind is that the role of policy-makers must be treated integrally with the planning effort itself; the success of the entire long-range planning strategy proposed herein depends very much on a fluid relationship between the two. It follows that this interface is an important aspect of the methodological design. This subsection proposes relevant guidelines.

The nature of our prescriptions for this interface rests on the following premise: the planning effort exists ultimately as an information-preparing instrument for the decision-makers (i.e., the Governor and legislators); the planning effort <u>per se</u> shall not make the ultimate decision

of selecting the master plan. Given this premise, the key guideline is that an active dialogue between the two must be sustained throughout the planning effort. By "active dialogue," of course, we infer a two-way street. In order to serve the decision-makers efficiently, the planning staff must recognize (and, to some extent, elicit) the types of criteria which the decision-makers consider most meaningful in evaluating alternative plans, even though such criteria will go beyond the engineer's traditional and convenient benefit-cost ratios. Similarly, the decision-makers should take full advantage of such a competent planning apparatus, by asking for whatever information might be desired and by cooperating, when feasible, with the planners' efforts to identify decision-making criteria. This mutual appreciation will avoid the pitfalls of some other transportation planning efforts, where a healthy interface has been precluded by the foregone conclusions of policy-makers or where the planning effort has examined such a narrow range of alternatives that decision-makers have found it necessary to take the matter of plan design into their own hands.

Quite a few studies, for example, have operated to produce just <u>one</u> transportation plan, which was "best" in the opinion of the planning staff. Said plan was then presented to decision-makers for what amounts to a mere ratification. This approach would have been appropriate only if those decision-makers had previously reached a clearly articulated concensus of goals for the planning effort to follow in

deriving what was "best". However, such an expression of goals has yet to materialize, to our knowledge, in any transportation planning study.

What has happened, then, is that decision-makers have tended to send such a plan back to the planning staff for major revisions. An inevitable pitfall of this situation is that the decision-makers tend to assume at least partial responsibility for designing the plan, and their attention tends to focus on the geographic location of various links and routes rather than on the myriad of consequences attendant to any revised plan. It is not unusual, furthermore, for this set of circumstances to propagate itself through repeated cycles, with links being added and deleted on a rather disorganized, piecemeal basis. The role of the planner thereby dwindles into oblivion. In some cases, this sort of situation has ended in a total impasse, with no plan being accepted by all.*

These kinds of problems can be expected to occur, no matter how competent the planning staff might be, so long as a prespecification of goals is lacking and so long as just one plan, nevertheless, is presented. The planning staff has no alternative, under these circumstances, but to follow

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* The recent history of transportation planning in Washington, D.C. epitomizes most of the points made here. See Arthur D. Little, Inc., Transportation Planning in the District of Columbia, 1955 to 1965: A Review and Critique, Cambridge, Mass., March 1966; and Wingo, L.W., Jr. and Perloff, H.S., "The Washington Transportation Plan: Technics or Politics?" Papers and Proceedings of the Regional Science Association, vol. 7, 1961.

its own values in the process of plan design. This approach directly violates the aforementioned premise of this design: it is the values of the decision-makers which must effectuate the ultimate selection of a Statewide master transportation plan.

Rather than becoming involved directly in decision-making responsibility, the proper function of PennDOT is to do what it can to promote viability in the decision-making process. The most crucial point to be made in this report is that PennDOT must prepare a meaningful range of alternative plans rather than to follow the precedent discussed above. We maintain that, if faced with a range of alternative plans (and a comprehensive summary of estimated consequences and capital costs of each) reflecting different weightings of evaluation criteria, policy-makers will tend to think more in terms of consequences and costs rather than in terms of a map of transportation facilities, and will be much more able to appreciate the tradeoffs between conflicting objectives. Such an appreciation would clarify the issues which represent the real choice variables, and would lead to an ultimate decision which considers very deliberately the interests of all parties. Furthermore, we believe that such a strategy generally would be well received by legislators.

Above we made the point that the presentation of just one plan is likely to result in a disorganized situation where dialogue with the planning effort breaks down in self-perpetuating feedback, conceivably to the extent that decision-

makers find themselves in an impasse. While we maintain that the presentation of a range of alternatives will reduce substantially the probability of impasse, we hardly infer that the need for feedback to the planning effort would no longer exist. Indeed, some readers may argue that the presentation of several alternatives would serve merely to complicate and lengthen the decision-making process. However, this would be the case only if the plan were a foregone conclusion in the first place, a strategy which cannot be expected from a legislature of Pennsylvania's quality. Of much greater significance is that the strategy we recommend would lead ultimately to a much more intelligent decision, regardless of whether that decision would be reached more or less expediently.

Now let us summarize briefly the preceding discussion on this interface problem. As pointed out repeatedly in this report, because it is so difficult to derive a meaningful prespecification of goals and because of the current limitations in analytical technique, a "best" plan for the Commonwealth can be derived only by means of a "search and selection" process. In other words, a range of alternative plans must be hypothesized and tested by the planning effort. Given our premise that the ultimate choice of a master plan is the proper responsibility of the legislative process, PennDOT's proper role is to promote the viability of that process. It can do so by presenting to decision-makers several of the most promising alternatives it has considered,

rather than to bury all other alternatives by presenting just one plan which the planning staff judges to be best.

In sum, PennDOT should have four major areas of responsibility in its role of serving the legislative process: (a) the identification of those decision criteria which the policy-makers deem most important (e.g., by means of a special legislative committee); (b) the generation and testing of a wide range of alternative plans and the reduction thereof to a set of several candidates which best represent that range (task 5); (c) the communication of that set, together with comprehensive information on the estimated consequences and capital costs of each alternative in the set (derived by task 6), by means of efficient displays; and (d) the accommodation of decision-makers' requests for the generation of still other alternatives if so desired. Except for pronouncing once again our recommendation against trying to summarize all consequences in terms of commensurate dollar units, we leave the problem of information organization to the PennDOT planning staff. From this point, we confine our attention to our recommended strategy for generating, testing, and evaluating on a preliminary basis a broad range of alternatives, using the forecasting model system described earlier.

## 2. The Overall Structure of Plan Design

As discussed in chapters II, V and VI, the operational state-of-the-art of transportation plan design continues to rely almost entirely upon the planner's subjective application

of a grease pencil. As a prelude to our recommendations, we must emphasize the importance of the PennDOT planning staff keeping in touch with the variety of research on this problem, particularly that of the Northeast Corridor Transportation Project, which is attempting a very thorough characterization of the task including the rather perplexing matter of relating multimodal transportation network configurations to patterns of regional socioeconomic development. All of this work remains in too premature a state for us to evaluate its potential for PennDOT.* The bulk of our recommendations are taken instead from recent research done for the Illinois Division of Highways, which in turn draws heavily upon techniques of multivariate statistical analysis.** This adaptation affords a much more objective formulation of highway plans. Pending the results of the current research mentioned above, the treatment of other modes must remain subjective.

Besides its overall objectivity, this adaptation is attractive because it is couched within the conventional highway classification framework which the Department of Highways employs to account for link improvement requirements. A useful remnant of the "highway planning surveys" methodology

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* For the most recent documentation of the NECTP work, see Shuldiner, P.W., "A Strategy for the Generation of Transportation Alternatives," U.S. Department of Transportation, Office of High Speed Ground Transportation, April 1968.

**Wegmann, F.J., "Two Approaches Towards Functional Highway Classification Policy Decisions with Application to Southern Illinois," Ph.D. Dissertation, Department of Civil Engineering, Northwestern University, Evanston, June 1967.

discussed in chapter III, the practice of highway classification typically involves the grouping of all state highway links into a hierarchy of several nominal categories, whereby all links in any given category shall be provided with the same level of service. Conventional practice accomplishes this grouping strictly on the basis of forecasted link volumes. Wegmann's model, by drawing upon statistical techniques for grouping observations (links) on the basis of many variables rather than just one, permits the broader concept of a "functional classification," whereby link characteristics such as average trip length, commercial vehicle percentage and trip purpose mix may be considered simultaneously with link volume. We have extended the concept further yet, to permit the consideration of variables related to a link's socioeconomic environment.

The use of this approach, which is tied integrally to the forecasting model system, to generate alternative plans is accomplished by varying the assignments of service levels to link groups and also by varying an artificial regional development variable. For clarity of exposition, we shall discuss the approach primarily in terms of the link volume variable alone. The extensions to the functional concept are noted after the mechanics of the technique are presented in terms of link volume.

Figure X-3 is a flow chart that shows the activities involved in hypothesizing transportation systems, their interactions and the relationship of this effort to the

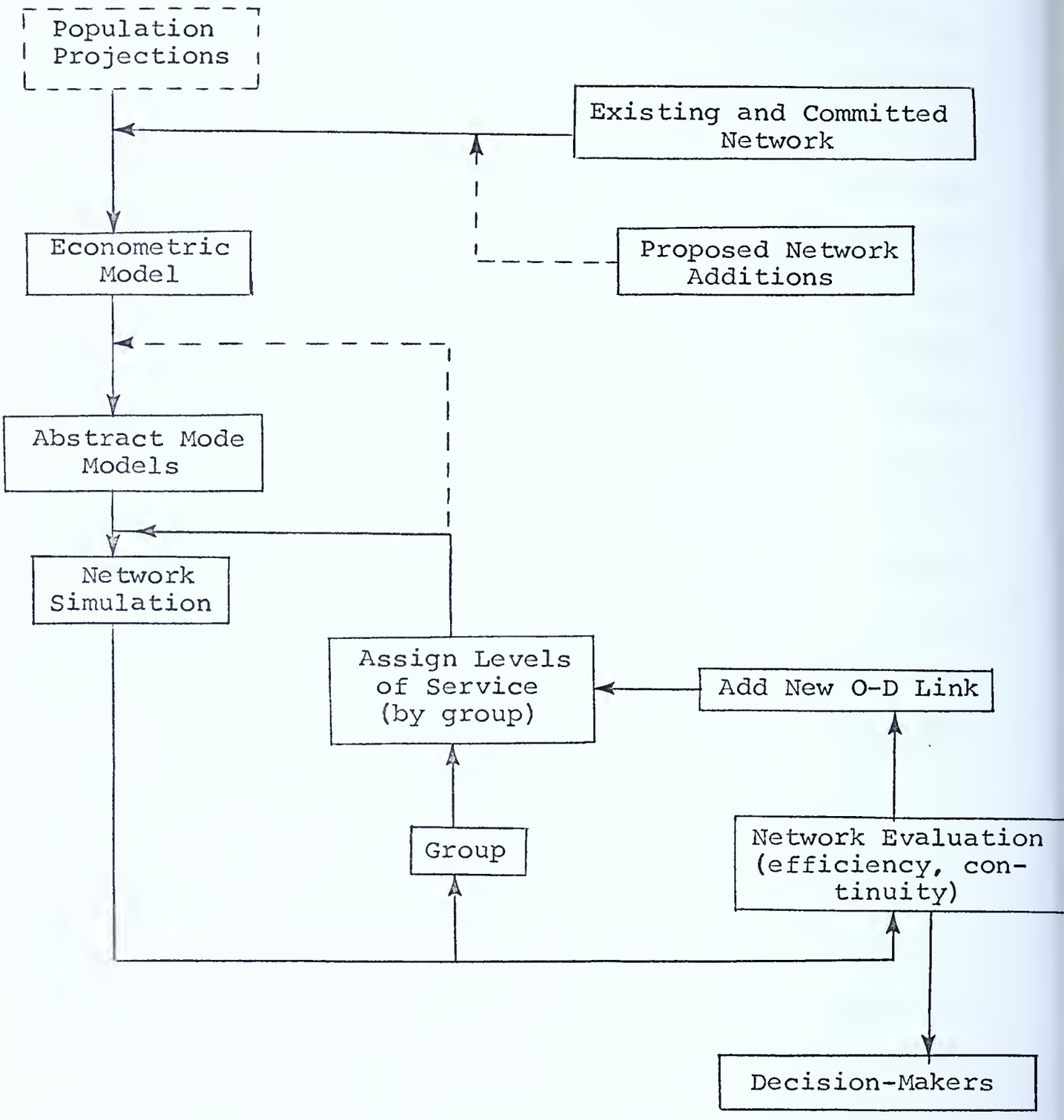


Figure X-3. Flow Chart of Network Design Process

forecasting model system.* The operation of the entire process is explained briefly first, followed by a detailed discussion of selected blocks.

The planning process is initiated by inputting the "existing and committed network" (along with the areawide "population forecasts") to the forecasting model system. "Proposed network additions," such as suggested from the State Highway Commission's hearings, could be added at this point but there is considerable interest in testing the existing and committed network without any further modification. The strategy then proceeds with each of the steps in the forecasting model system through "network simulation." The outputs of this model are used in two different ways. "Link grouping" involves the ranking and/or classification of network links, in terms of traffic volumes and other functional performance characteristics. The "network evaluation" step applies two shorthand criteria that lead to modifications in network configuration. One measure is efficiency, defined in reference to a pseudo-ideal pattern of origin-destination trajectories. The other measure is intramodal continuity. Inspection of these measures prompts the assignment of link improvements to the defined link groups. A level of service is then assigned to each group and the process returns to the forecasting model system to test the revised network.

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* The Freight Modal Split and Passenger Demand Models are represented in the figure by just one block, entitled "Abstract Mode Models."

## 3. Elaboration of the Plan Design Process

### a. Existing and Committed Network

The design process is initiated by entering a characterization of the existing network. The description of this (and the committed) network shall be in terms of level of service and capacity parameters as discussed in chapter VI. Individual links in the network may have a one-to-one correspondence with highest types of physical facilities (such as the Interstate system), but generally represent aggregations of physical rights-of-way into "corridor" representations as discussed in chapter V.

### b. Proposed Network Additions

This is a "suggestion box" through which the planner may introduce radically different designs, such as an extensive rail system or new technologies. Note that it enters the forecasting model system at the highest level, as it may be supposed that these are changes that would have significant land-use and traffic-generation effects. In principle, additions of this sort could be introduced through the "Add New Origin-Destination Links" block, but this approach would bypass the first three models in the forecasting model system. The task of adding new O-D links is intended for more incremental modifications.

### c. Grouping

Grouping, sometimes called classifying, is the ranking of links (by mode) in the order of their "importance," then dividing them into a number of distinct categories. In

general, the ordering should be by "functional importance" based on such factors as traffic flow, trip length, commercial vehicle composition, priority for work trips, etc. For ease of understanding we discuss the plan design strategy in terms of volume alone.

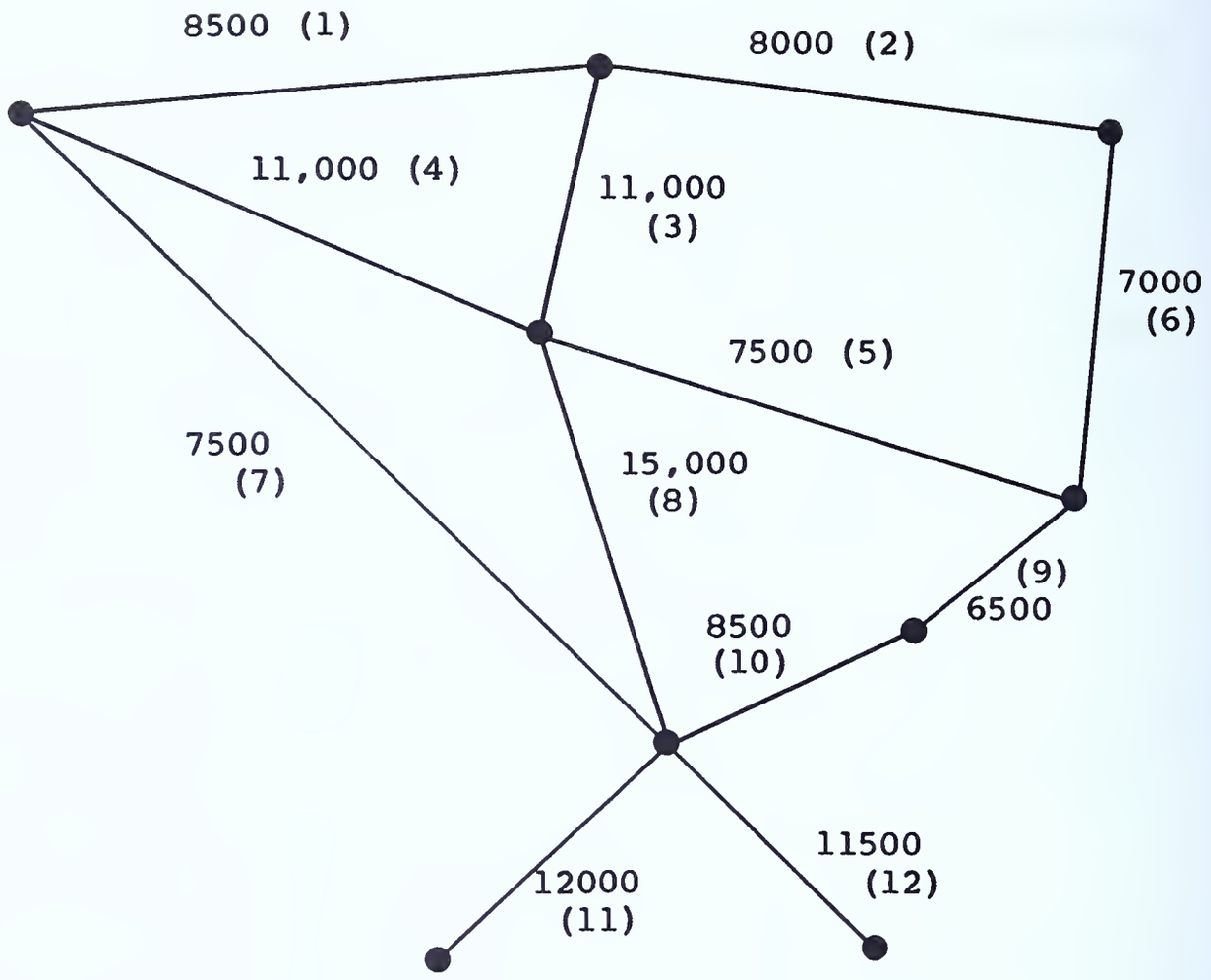
Assume a network comprising twelve links connecting a set of nine nodes, and that the assignment model has yielded traffic flows as shown in Figure X-4. We now list these in order of traffic volume:

| Link Number | Volume | |
|---|---|---|
| 8 | 15,000 | |
| 11 | 12,000 | |
| 12 | 11,500 | Group I |
| 3 | 11,000 | |
| 4 | 11,000 | |
| 1 | 8,500 | |
| 10 | 8,500 | |
| 2 | 8,000 | |
| 5 | 7,500 | Group II |
| 7 | 7,500 | |
| 6 | 7,000 | |
| 9 | 6,500 | |

These are next stratified into some number of groups. Let us suppose that this is a highway system and that we wish to have two groups that can be assigned different levels of service. The line might be drawn between link 4 and link 1, as indicated above, giving the network of Figure X-5.

### d. Network Evaluation Criteria

Two criteria, efficiency and continuity, are recommended that provide a check on the quality of the design and that lead directly to making improvements. Efficiency is defined




7000 = average link volume (6) = link number

Figure X-4. Link and Node Network for Grouping Example

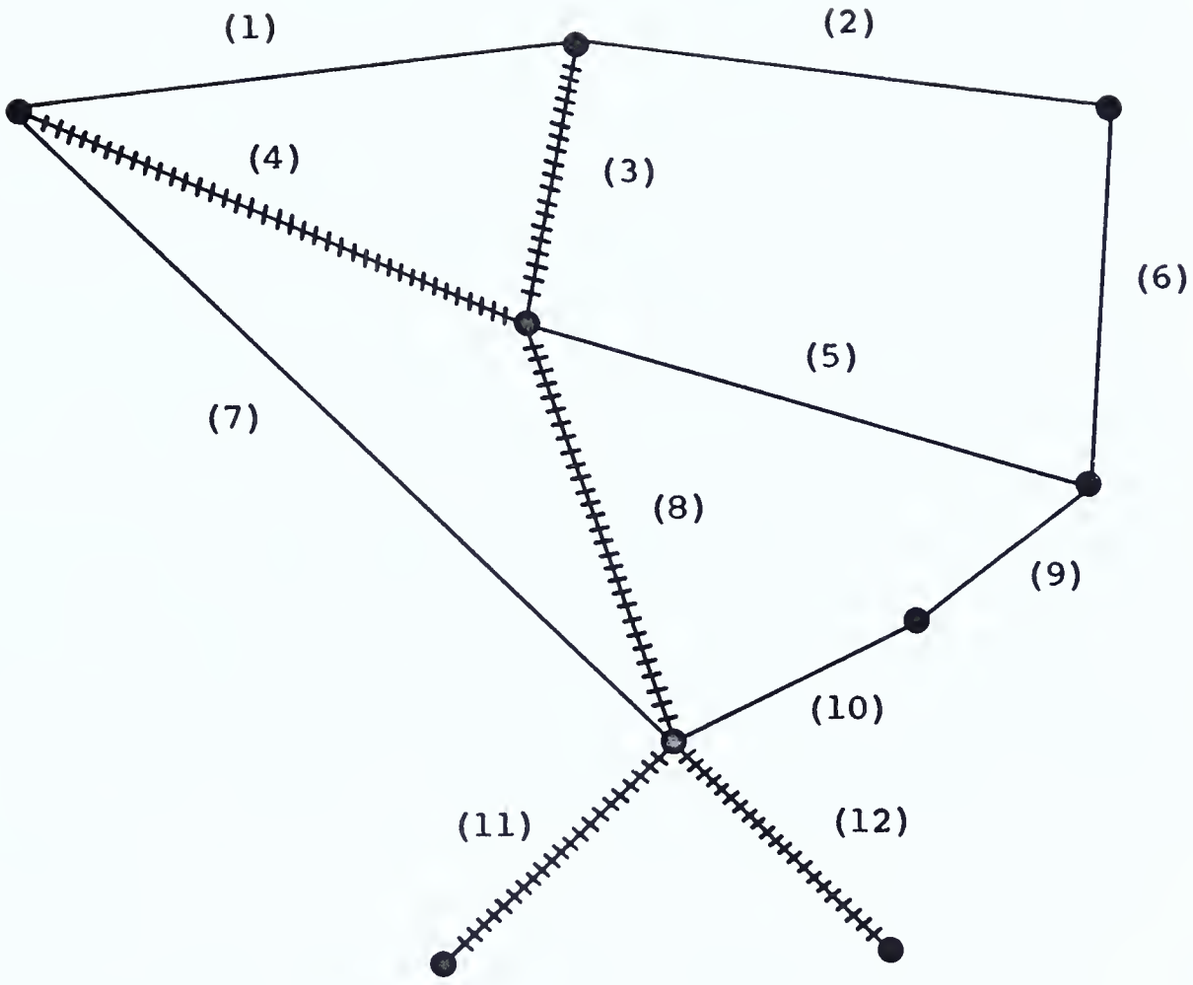



Figure X-5. Network Groups Based on Traffic Volume

here in a general sense as a measure of the time or distance actually traveled, compared with the shortest route between origins and destinations. The shortest route may be defined, depending on the purpose, as the shortest physical route available or as airline distance. The latter seems more useful in indicating the need for new links and the former for showing the need for a higher level of service, as measured in time units, on an existing link.

The measures to be found in the published literature, whether called efficiency, circuity, diameter, access or dispersion,* attempt to give a single figure for the entire network. We are interested, rather, in measures applying to individual origin-destination pairs. The following is proposed as a suitable efficiency measure for this purpose. Efficiency is defined, for a given O-D pair, as follows:

$$E = \frac{d\Sigma f_k}{\sum_k d_k f_k}$$

where $d$ = airline distance (time or distance)
$d_k$ = distance along $i^{th}$ route
$f_k$ = flow per unit time

An example of an efficiency calculation, based on mileage only, is given in Figure X-6. A similar computation could be made using travel time by assuming some average speed over the airline link.

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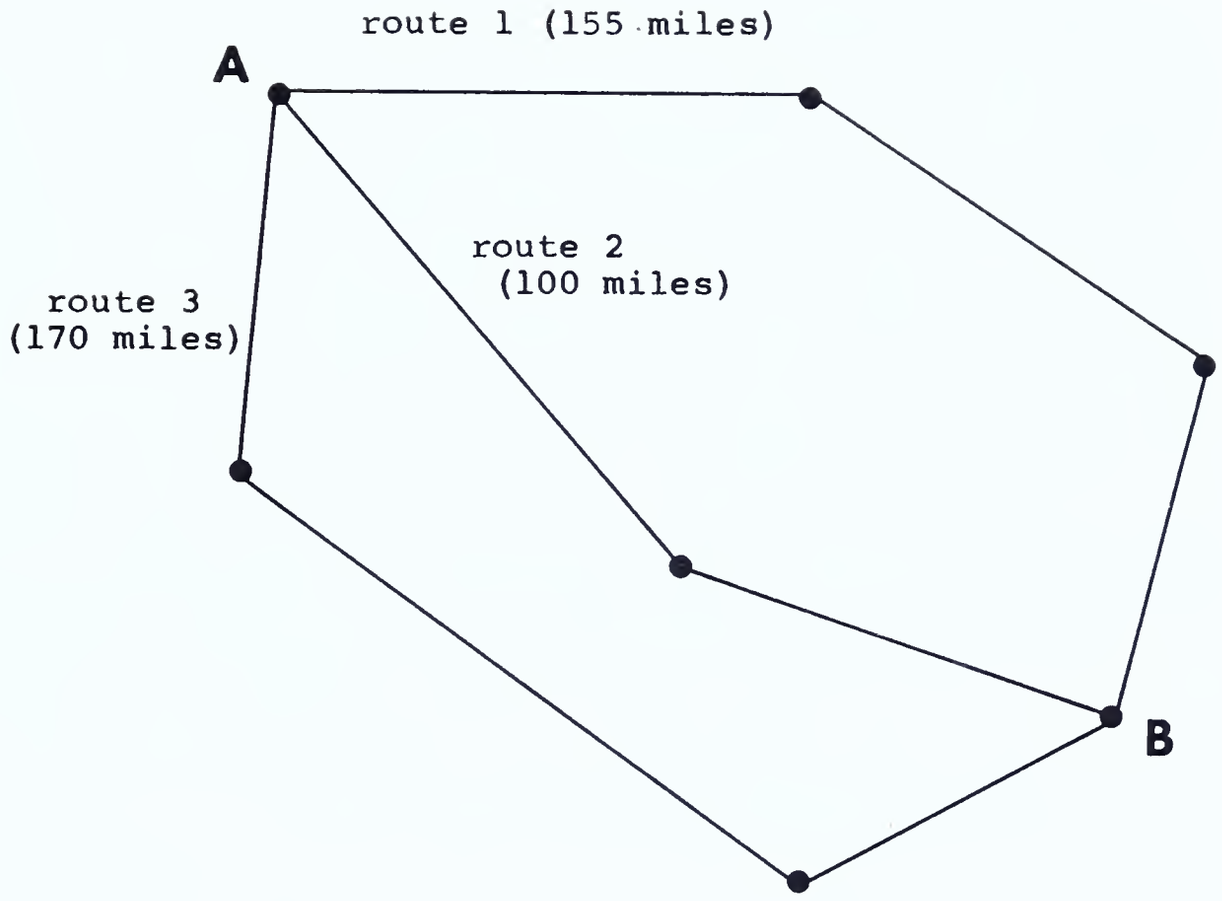
* Kansky, K.J., Structure of Transportation Networks, Research Paper No. 84, Department of Geography, University of Chicago, 1963.




Traffic distribution:

12,500 trips/day
from A to B

Traffic assignment:

| route | trips/day |
|---|---|
| 1 | 2700 |
| 2 | 6800 |
| 3 | 3000 |

Airline distance from A to B = 85 miles

$$E = \frac{(85)(12,500)}{(155)(2700) + (100)(6800) + (170)(3000)} = 0.661$$

Figure X-6. Example of an Efficiency Calculation

The continuity criterion has significance in two respects. One may be termed "continuity of mode" and the other "continuity of level of service." The disbenefit of a break in continuity is obviously greater for the first kind. Level of service continuity within a mode would seem to apply mainly to the highway network. It is the question of changing from, say, freeway to arterial highway, and perhaps back again in traveling between an O-D pair. The importance of continuity of level of service is hard to quantify, although there is evidence that a change to a lower level of service increases the accident rate for a given traffic volume. Sometimes the criterion is used that a freeway network should have no stub ends, even if traffic flow is light over some portions of it, or at least one should consider inserting connecting links.

### e. Add New O-D Links

The purpose of this block is to add new direct links between O-D pairs where shown to be needed by the efficiency and continuity criteria. By this we mean links at a level of service at least equal to the lowest considered for this relatively high-level planning and do not mean to count lower level paths that may happen to exist. The intent is to supply the "fine-grained" additions and adjustments to the broad plans supplied by "proposed network additions". No specific quantitative values of continuity or efficiency

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* Wegmann, F.J., op.cit.

are suggested here. This is left to the judgment and experience of the network designer. An example shows how this decision might be made.

Suppose that for the network of Figure X-6 we denote the additional nodes C and D and consider the possibility of adding a direct link between them (Figure X-7). The assumed origin-destination flows for this pair of nodes is given, along with route flows over the two feasible routes. This is compared with the cost of the same flow over a (new) direct link.

The importance relative to other links might be shown better by multiplying the inverse of efficiency by the traffic flow. Thus

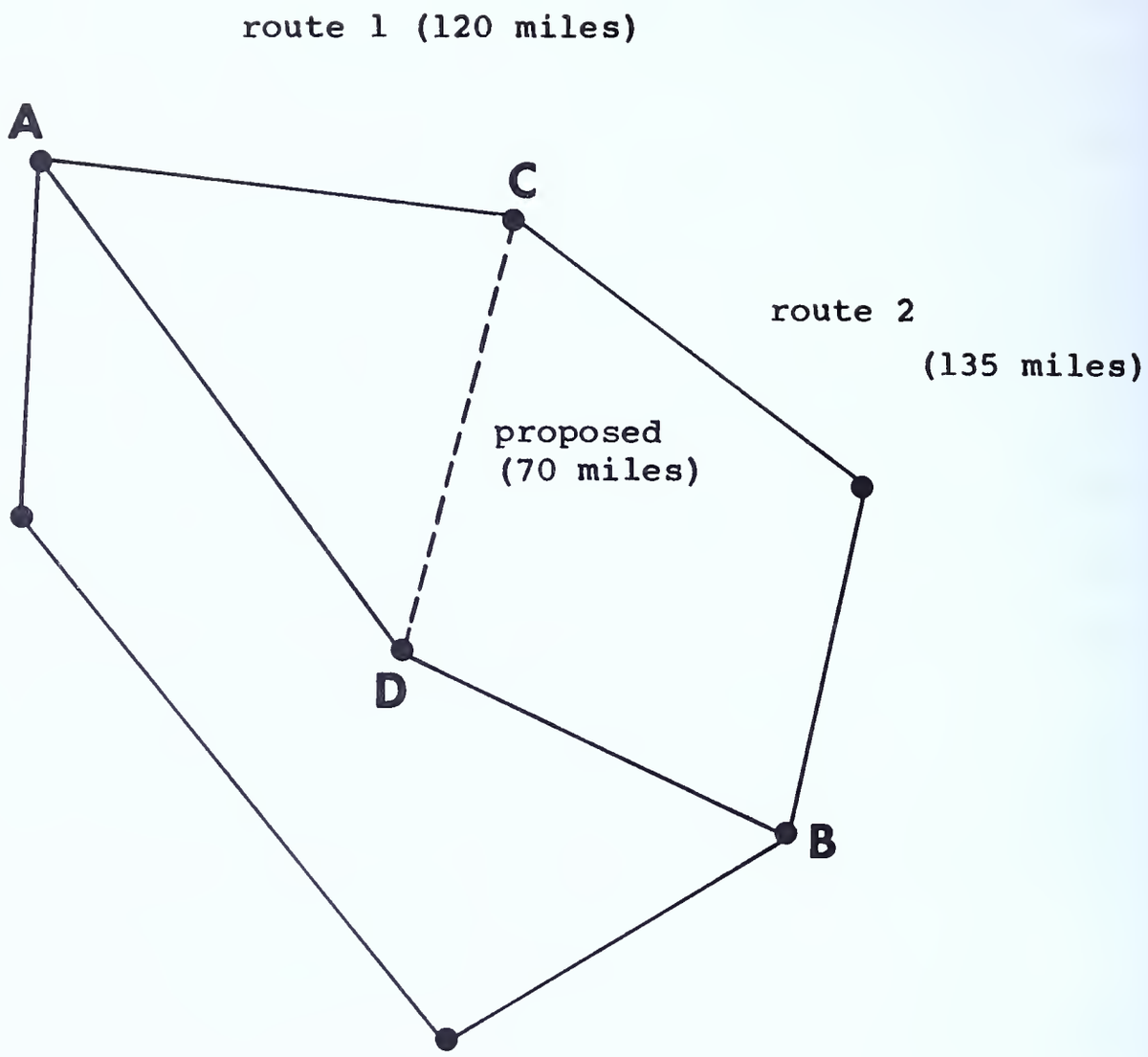
$$\text{"importance"} = \frac{\text{total O-D flows}}{\text{efficiency}}$$

which for the example would be

$$\frac{(120)(4700) + (135)(1700)}{70} = 11336$$

Note again that the "distance" measure might more appropriately be time, but that actual mileage is used here for simplicity.

The added links are, on the basis of judgment, placed into one of the groups that have already been formed. At this point one may also choose to place some previously existing links in a higher group in an effort to improve efficiency, while perhaps moving others to lower groups.




| Traffic distribution | Traffic assignment | |
|---|---|---|
| 6400 trips/day from C to D | route | trips/day |
| | 1 | 4700 |
| | 2 | 1700 |

$$E = \frac{(70)(6400)}{(120)(4700) + (135)(1700)} = 0.565$$

Note:

Flows for this group of nodes are given along with route flows over the two feasible routes. This is compared with the cost of the same flow over a (new) direct link.

Figure X-7. Sample Efficiency Calculation

f. Assign Level of Service

Through the choice of a level of service for each of the groups that have been developed, the planning staff can develop a number of variations for each basic system. The basic aim is to meet some level of service constraints, based on traffic flow, by choosing facilities of appropriate capability. However, the opportunity is here to experiment with higher or lower levels, making possible a sensitivity analysis.

As an example of a level of service assignment, let us take the data previously listed and divide it this time into five groups:

| Link Number | Volume | |
|---|---|---|
| 8 | 15,000 | Group I |
| 11 | 12,000 | Group II |
| 12 | 11,500 | |
| 3 | 11,000 | |
| 4 | 11,000 | |
| 1 | 8,500 | Group III |
| 10 | 8,500 | |
| 2 | 8,000 | |
| 5 | 7,500 | Group IV |
| 7 | 7,500 | |
| 6 | 7,000 | Group V |
| 9 | 6,500 | |

Now designate several levels-of-service (not necessarily five) ranging perhaps from eight-lane, limited access freeway down to a good two-lane highway. We designate these as levels A,B,C,.... Several possible systems might then be proposed as follows:

| Group | 1 | 2 | 3 |
|---|---|---|---|
| I | A | A | B |
| II | A | B | B |
| III | B | C | C |
| IV | B | C | D |
| V | C | D | F |

The costs of these three plans would be different (plan 1 being the most expensive) and the benefits would presumably vary in the same order.

### g. Use of the Plan Design Strategy Iteratively

It could be reasonably assumed that the basic network, as determined by "existing and committed network" plus "proposed network additions," along with the (transport insensitive) regionwide population forecasts, essentially determines land use and traffic generation. Level of service changes and new links would cause some "shifted traffic," as determined by the upper three forecasting models. The assignment to particular routes and the resulting link traffic is obviously most sensitive to these "fine-grained" changes. This need for feedback to route assignment is provided as indicated by the arrow (Figure X-3) returning to the Simulation.

## 4. Functional Importance

The aforementioned methodology was built around the flow chart of activities shown in Figure X-3, to which we refer once again. In the description of the block labeled "group," the "functional importance" was used, but the only measure suggested was link traffic volume. We now expand the definition of functional importance to include other

dimensions. The discussion applies in principle to all modes, but is currently most meaningful for highway grouping or classification.

As a first step, consider the question of functional importance of commercial vehicles as compared with automobiles. Clearly the commercial vehicles are more demanding of facilities and should be "weighted" in some way. This is often done by assigning a value of so many "equivalent automobiles," thus recognizing their greater importance in planning while maintaining traffic volume as the measure of importance.

Other dimensions that have been suggested* are number of work trips and length of trips. That is, it may be considered important to give higher levels of service for work trips and for travellers making long trips than for other kinds of travel. National defense service has also been suggested as a dimension of functional importance, although perhaps is harder to quantify than the others. Other factors could be introduced relating to land use and development objectives, or to political objectives. This would allow the planner or decision-maker to introduce a dimension of importance with arbitrary values that would effectively force certain links to be placed in a higher group than would otherwise be the case. The resulting plan would still be rational in the sense that iteration through

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* Wegmann, F.J., op.cit.

the forecasting models would lead to an equilibrium solution that equalizes level of service within functional groups and tends to minimize costs.

There is no difficulty in comparing two links on the basis of traffic flow; if this is the only factor to be considered the criterion is single-dimensioned or scalar and a unique ordering is possible. If, as suggested above, commercial vehicles are given a weighting in terms of equivalent automobiles, then the manual ordering is still feasible. The other criteria suggested are not commensurate with traffic flow, however, and we must now deal with a "functional importance vector." This might be expressed as the vector below, which happens to have eight dimensions:

$$\text{functional importance} = \begin{bmatrix} \text{traffic flow} \\ \text{percent commercial vehicles} \\ \text{trip length characteristics} \\ \text{land use importance} \\ \text{development characteristics} \\ \text{political importance} \\ \text{national defense} \\ \text{other factors} \end{bmatrix}$$

These eight dimensions together measure functional importance.

The difficulty stemming from this approach is now clear: there is no unique way to order vectors. Two general approaches are used. One is to assign weights to each of the factors and forms a scalar sum. If the factors are denoted by $f_1, f_2, \ldots f_n$ and the weights by $\alpha_1, \alpha_2, \ldots \alpha_n$, then

$$\text{functional importance} = \sum_{i=1}^{n} \alpha_i f_i$$

If $f_1$ = traffic flow, letting $\alpha_1 = 1$ and $\alpha_2 = \alpha_3 \ldots = \alpha_n = 0$ would correspond to basing functional importance on the single dimension of traffic flow. The other approach involves the application of a multivariate statistical technique (including factor and discriminant analysis) to group links directly. This second strategy is both more formal and more objective, and is documented well in Wegmann's dissertation.*

## D. Summary

This chapter has concentrated on two aspects of the proposed planning methodology that have been largely neglected in preceding chapters: the coordination and integration of the individual models. The lack of attention to these topics in earlier chapters is not meant to imply that they are less important than the operations of the individual models, but rather that a comprehension of the workings of the individual parts of the model system is necessary before the impacts of the overall integrated operation can be appreciated.

The earlier section of this chapter, dealing with the coordination of the model system, was designed to show how the integration of the system and the iterative procedure employed in its operation produce the dynamic transportation sensitivity desirable for the planning effort. The use of transportation variables to make predictions in each of the models, and the iterative process whereby these variables are continually modified by traffic volumes and network changes, are responsible for this feature of the system.

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* Wegmann, F. J., op. cit.

A dominant theme throughout the chapter was that, while the methodology proposed herein is a valuable tool, the ultimate value of its predictions will be determined by the skill of the people charged with its operation, and their experience with the model system. The discussion also indicates that the methodology has not answered all the questions that have been raised throughout the study, indeed, it undoubtedly has not asked all the questions that will arise during the implementation period. However, some direction has been implied where problems have been identified. The solution of these problems must rest with the planners and with the experimentation with the system to see how it reacts to different conditions.

# XI
# IMPLEMENTATION OF THE METHODOLOGICAL DESIGN

The previous four chapters have presented in detail all components of the entire PennDOT methodological design and the interfaces between those components. While their implementation has been discussed insofar as strategies for parameter estimation are concerned, nothing has been said about how this implementation effort should be staged through time. Obviously, the entire design cannot be rendered operational in six months or a year. The staging of this implementation has been an integral consideration of this study, and is discussed in this final chapter.

The overriding design criterion for this temporal staging (and its implications to individual model designs) was to allow for as smooth a phase-in as possible, taking as given the Commonwealth's current planning methodology as discussed in chapter IV of Part One. Two motives lay beneath this criterion. First, it has been assumed that most of the PennDOT planning staff would consist of those Commonwealth personnel already engaged in some facet of the State's transportation planning activities. These staff members must be eased into the new techniques proposed herein, so that maximum use is made of their talents. Second, the sooner more comprehensive solutions can be derived for Pennsylvania's transportation problems, the lower the total social cost*

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* For our definition of social cost, see the footnote on page 152.

will be. Accordingly, we have arranged the implementation strategy so that those components concerned directly with the estimation of travel patterns (direct effects) and with highway planning shall be operationalized first, while the Econometric Model shall be the last component to be implemented. In the intervening period, the scope of the planning effort shall be increased as more data are collected and analyzed.*

The proposed implementation strategy calls for an estimated $7,150,000 to be spread over a period of 60 months. These estimates are biased heavily to the conservative side, including a $1,000,000 "Threshold and Contingency" fund to be drawn upon in case of severe snags either in initiating the entire effort or during the five-year period. The entire effort may be performed "in-house" by PennDOT staff or substantial portions may be contracted to transportation consultants. We assume here that most work will be let to independent contractors, and our cost estimates allow a 10% profit. Resources for additional staff with specialized expertise have been designated for the purpose of monitoring and managing the overall program.** A greater emphasis on "in-house" participation affects only the distribution of the total resources between the technical tasks and the monitoring and managing effort.

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* Note that this approach is quite contrary to the California study design developed by North American Aviation, which called for implementation of its "Population Model," its "Econometric Model" and its "Land Use Model" before any development of transportation models.

**Total resources for this continuous effort are $1,000,000.

The staging of the implementation is divided into ten major tasks, in addition to the monitoring and managing effort:

| Task | Description |
|---|---|
| A | Review of Methodological Design |
| B | Synthesis of Existing Data |
| C | Data Collection Design |
| D | Data Collection |
| E | Link Grouping Model |
| F | Network Simulation Model |
| G | Passenger Demand Model |
| H | Freight Modal Split Model |
| I | Econometric Model |
| J | System Integration |

The specific temporal interfaces between these ten tasks are depicted in Figure XI-1, and their estimated dollar costs are listed in Table XI-1. Note that heavy emphasis is placed on the problems of data management and system integration. Each of the steps is reviewed in greater detail below.

## A. Review of Methodological Design

Once the PennDOT planning staff is organized, including the hiring of six to eight additional professionals highly skilled in transportation and economic development planning, the first six months of the implementation effort will have these and other key staff members reviewing our design in detail. Any modifications and/or refinements deemed necessary shall be documented during this period and the implementation program shall be revised accordingly. A total of $70,000 has been allocated to this effort, encouraging the involvement of twelve or so staff members in total, or several

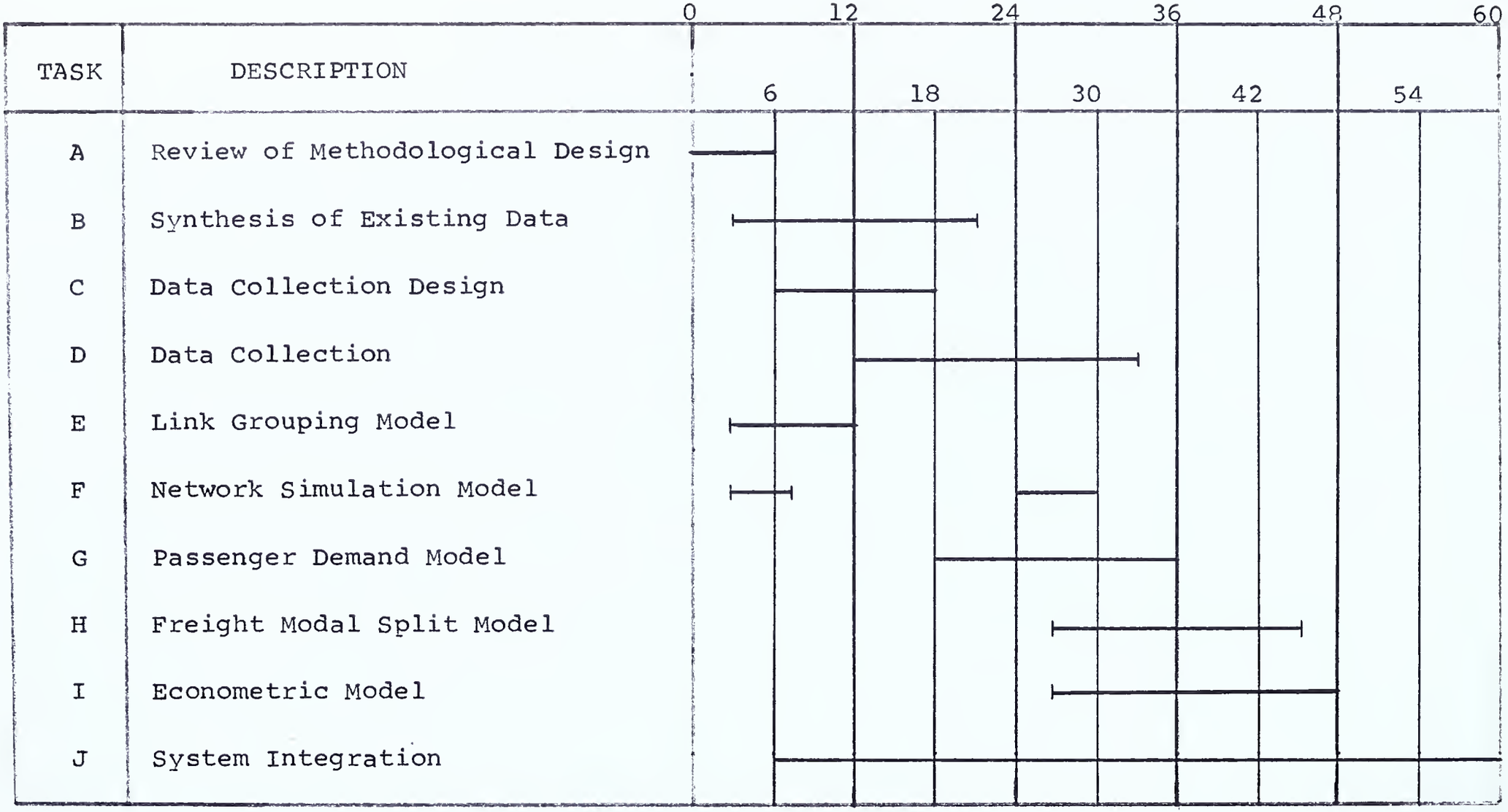


Figure XI-1. Implementation Program Plan

| Task | Description | Estimated Cost |
|---|---|---|
| A | Review of Methodological Design | $ 70,000 |
| B | Synthesis of Existing Data | 200,000 |
| C | Data Collection Design | 200,000 |
| D | Data Collection | 3,000,000 |
| E | Link Grouping Model | 60,000 |
| F | Network Simulation Model | 80,000 |
| G | Passenger Demand Model | 100,000 |
| H | Freight Modal Split Model | 90,000 |
| I | Econometric Model | 500,000 |
| J | System Integration | 850,000 |
| | Monitoring and Management | 1,000,000 |
| | SUBTOTAL | $6,150,000 |
| | Threshold and Contingency Fund | 1,000,000 |
| | TOTAL COST | $7,150,000 |

Table XI-1. Estimated Program Cost

individual consultants if desired. While these resources are directed to "in-house" operations, they have been separated from the continuing task of monitoring and managing for convenience.

## B. Synthesis of Existing Data

As early as three months after the initiation of the implementation effort, a thorough inventory and synthesis of existing data shall begin, and shall continue for 18 months involving a total expenditure of $200,000. Several key areas must be covered by this activity, most of which relate to the establishment of freight analysis zones and their reconciliation with the given passenger analysis zones. All primary sources of county economic data shall be procured and analyzed by a regionalization computer program (see chapter VII) to define the freight zones upon which the commodity movements survey will be based. Also, appropriate prorating schemes shall be developed to permit the transformation of socioeconomic data from freight to passenger zones (see chapter VIII) and of origin-destination data by freight mode from freight to passenger zones (see chapters IX and X). Furthermore, all non-highway passenger flow data should be prorated or summarized (whichever the case may be) to a passenger zone basis. Finally, the synthesis of available (be it very limited) freight flow data from the Census of Transportation and the Interstate Commerce Commission, supplemented by a variety of simplifying assumptions, will form a very crude bank of data for exercising the Freight Modal Split Model immediately after it is programmed.

## C. Data Collection Design

Upon completion of Task A, at which point all data requirements will be finalized, the very crucial problem of designing all survey work will be initiated. We have allocated $200,000 to this task over a period of twelve months. Most of these funds shall be spent before initiating the surveys themselves (Task D), to work out detailed sampling procedures. The remaining expenditures shall be directed to the design of appropriate information processing software. For sound data management, it is essential that those personnel to be responsible for the implementation of individual forecasting models be directly involved in this data collection design task.

## D. Data Collection

The substantial requirements for more data have been pronounced repeatedly in previous chapters. The role of such additional information is central to the entire methodology, and the sheer magnitude of these requirements calls for nearly half of the total implementation budget. Specifically, we have budgeted $3,000,000 to be spent over a 21 month period beginning with the thirteenth month in the implementation period. As discussed in the previous chapters (e.g., section VI-C), two major survey areas are involved here. First, and by far the largest, is the commodity movements survey which will request interindustrial origin-destination data of selected Commonwealth shippers by questionnaire, in a manner similar to the strategy of the

Philadelphia input-output study. This survey will also establish commodity prices and transportation costs (by mode). The second survey effort shall involve a program of interviews at terminals of non-highway modes to determine the access patterns (presumably by highway) of such trips. Both surveys should be initiated during the thirteenth month; results of the access patterns survey should be available by the end of the 24th month, and the commodity movements study should be completely processed by the end of the 33rd month.

## E. Link Grouping Model

The "Link Grouping Model" refers to the mathematical classification strategy detailed in section X-C ("Network Design and Evaluation"). As described in that section, the technique is readily adaptable to Statewide highway planning with only some minor modifications to the Bureau of Public Roads traffic assignment model. This analytical link classification strategy will call for the expenditure of $60,000 over a period of nine months for its complete implementation. However, its application to Statewide highway planning will require only a six-month effort, assuming that appropriate modifications to the BPR model (see Task F below) are made concurrently. Since no additional data are required to apply this network design technique, it shall be initiated as early as possible; we have allowed three months for the review effort (Task A) to verify its value. The effort will consist largely of computer programming

to adapt a factor analysis and grouping program (packages are available) to the specific problem, and the exercising of the modified package to evaluate alternative highway networks.

## F. Network Simulation Model

As indicated in the preliminary comments of this chapter, the forecasting model system shall be phased into operation in the reverse order of which its components were presented in the four previous chapters. The implementation of the Network Simulation Model, as shown in Figure XI-1, is divided into two segments. The first, the initiation of which coincides with the Link Grouping Model, shall involve staff familiarization with the BPR assignment model and the modification thereof to summarize the trip length and commercial vehicle composition characteristics of highway link flows. This four-month effort can then be integrated with the interim results of Task E to objectivize Statewide highway planning as discussed above. The second effort (of six months' duration beginning with the 25th month) will involve further programming modifications to the BPR package as outlined in Figure IX-4, to process the access travel patterns of predominantly non-highway modes and other peripheral improvements. The two segments will require $30,000 and $50,000 respectively, for a total expenditure of $80,000. Again, we emphasize the fact that this Task together with Task E shall have impact upon Statewide highway planning methodology within nine months after the implementation effort has begun.

## G. Passenger Demand Model

Tasks G and H involve the implementation of the "abstract mode models" described in chapter VIII. Because of the prior availability of the passenger access data to be surveyed, the development of the Passenger Demand Model shall begin first. The model shall be programmed between the 18th and 24th months, and initial empirical analysis shall begin at the 25th month, when the aforementioned data become available. For the remaining twelve months, the model shall be subject to extensive empirical analysis to determine independent variables of significant influence, and the calibrated model will be exercised for various hypothetical future network characteristics. Total resources for this Task are $100,000.

## H. Freight Modal Split Model

As of the end of the 33rd month, all commodity flow data will have been synthesized, and the development of the Freight Modal Split and Econometric Models can proceed. The implementation of the Freight Modal Split Model shall follow a pattern identical to that outlined for the Passenger Demand Model above (except that commodity groupings may be revised as an additional degree of freedom in the empirical analysis). Beginning with the 28th month, the model shall be programmed. Six months later, full-scale empirical analysis shall be initiated, the model shall be exercised with hypothetical network characteristics and finalized by the end of the 42nd month. Total resources for this Task are $90,000.

## I. Econometric Model

The implementation of the Econometric Model shall begin concurrently with that of the Freight Modal Split Model. The total amount of resources to be allocated to this Task is $500,000, to be spread over a period of 21 months. The first nine months of this effort shall consist largely of computer programming, while the latter 12 months will involve elaborate empirical analysis and theoretical refinement of the model. Such refinements might include, for example, alternative forms of the model's objective function and/or industrial production functions. Included in the latter 12 months would be such substudies as the preparation of schemes for projecting transportation costs, for forecasting export trade and for anticipating changes in interindustrial technological structure.

## J. System Integration

As discussed in chapter X, which went to great lengths in describing the specific interfaces between the entire design's many components, the need for very careful and deliberate integration of all components into a total system cannot be overemphasized. The task of System Integration, therefore, has been assigned a very important role in the implementation program, calling for a total of $850,000 spread throughout the implementation period from the completion of Task A on. Essentially, this Task shall be concerned with checking out the overall model operation and validation of compatibility at various points during the last 54 months

of the entire effort. This integration process will peak at various stages, reflecting the calibration and testing of another model in the forecasting model system. Specifically, beginning with the seventh month the Link Grouping Model and the "first segment" of the Network Simulation Model shall be integrated and applied directly to highway planning. At those milestones where the various forecasting models are programmed, pilot runs shall be operated in order to test the compatibility of direct sequential relationships and feedbacks (the ends of the 24th and 33rd months). Real-data runs of a parallel nature shall take place beginning with the 37th, 43rd and 49th months, with the last year devoted entirely to perfecting the integrated methodology and operating the entire system to evolve alternative candidates for a long-range Master Plan per chapter X.

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